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OF THE

AMERICAN WELDING SOCIETY

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American Welding Society

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AMERICAN WELDING SOCIETY

ESTABLISHED 1919

JOURNAL

Volume 5 JULY, 1926 Number 7

FALL MEETING

Continued progress is being made to develop a program which will assure the success of every important event at the fall meeting of the Society, which will be held in Buffalo on Nov. 17, 18 and 19. Plans should be made by every member of the Society who can do so to attend this important meeting.

WELDING STEEL STRUCTURES

The Sunday, June 27, supplement of the New York *Herald-Tribune* featured an article, entitled "Welding Process Hailed as Muffler on Din of All Steel Riveting." Various subheads include: "Practical Tests Assure Success of New Methods," "Reduced Cost Spurs Interest of Contractor," "Public Welcomes Relief from Air Hammer's Assault on Nerves and Ear Drums." Public acknowledgment is made in various parts of this article to the work of the American Welding Society.

Members of the Society will be pleased to note that considerable progress has been made in interesting the American Institute of Steel Construction to jointly undertake a comprehensive investigation in this field. As an opening wedge, the secretary of the American Bureau of Welding has been requested to present a paper on the possibilities of welding in this field at the annual convention of the American Institute of Steel Construction during the latter part of October.

As soon as the summer vacation periods are over, progress will be made in the organization of a suitable sub-committee, which will have active charge of the work. Possibilities to the welding industry and everyone connected with it from the extensions of the use of welding in this field are enormous.

WELDED RAIL JOINTS

The Executive Committee of the Committee on Welded Rail Joints held a meeting on June 29 at Lehigh University, Bethlehem, Pa. The committee witnessed the procedure to be employed at this university in making hundreds of shear tests on short sections of welded joint plates to rail, in an effort to develop, if possible, an improved type of plate and seam which will give the best results. This information will also be of considerable value to the structural engineer as determining the shearing strength of welded joints.

Attention was also given by the committee to laying out a scientific program to determine the stresses in rail joints under varying degrees of service and the possible duplication of these stresses in a testing device such as the repeated impact testing machine.

YEAR BOOK

The next issue of the JOURNAL will be devoted to the first Year Book of the American Welding Society. During the past several years the Membership Directory of the Society has been published as the August issue of the JOURNAL. This year it will be extended considerably and much valuable information concerning the Society incorporated in the Year Book. The latest addresses and connections of all members of the Society will be taken from the filled-in card recently sent out to the membership for this purpose.

WELDING OF MOKELUMNE RIVER CONDUIT

(*Editorial appearing in July 8, 1926, issue of* IRON AGE)

To the Editor: I notice in your issue of June 3 an article in connection with the Mokelumne River conduit in California, which article is headed "Favors Riveted Pipe Line."

Anyone glancing at this would come to the conclusion that the East Bay Municipal Utility District, Oakland, had changed from welding of

the pipe itself to riveting. As a matter of fact, this is not true. They have changed, it is true, from the welding of the girth seams in part of this line to riveting. The reason for the change to the riveted joint on the girth seams was to eliminate any possibility of locked-up stresses causing difficulty in the line because of change of temperature of the water or of atmosphere. It is the hope of the engineers that the riveted joints will act as expansion joints to some extent and relieve these stresses.

I believe it is safe to say that the engineers are very anxious to weld the girth seams and that they are taking steps at the present time so that most of this pipe line will not only have the longitudinal seams in the pipe itself welded, on which there never has been any question, but also they expect to weld the girth seams by the electric process in a way which will entirely eliminate the shrinkage stresses, which the previous gas process (which was used at first) introduced.

It is only fair to say also that there has been no proof whatsoever, from the tests which have been conducted, that the welding of the girth seams with the gas process is not entirely successful. In fact, the result of the first and only test which has been put on any section of the completed line shows definitely that, at a pressure above the highest working pressure which will ever be put on, there is not a single leak in any part of the line where the longitudinal seams have been welded with the arc process and the girth seams with the gas process.

There is not the slightest doubt that riveted girth seams will introduce the difficulty of leaks to a large extent, and it is only because of the fear that something might happen that this change in process has been made in the girth seams. There is no indication whatsoever that any such result has occurred, or will occur in the future, and I think it is safe to say that the change was made entirely because of the fear that something might happen rather than from any possible indication that anything would happen.

J. F. LINCOLN,
Vice-president, Lincoln Electric Co.

(Note by Editor *Iron Age*.—The article in *The Iron Age* of June 3 sustains the contentions of Mr. Lincoln. We agree with him, however, that the heading to that article was not fully descriptive of its contents and we are glad to print his letter to correct in a prominent way any misleading views which may have been gathered regarding the question.)

ARTICLE ON WELDED BOILERS AND CONTAINERS

The article on "Autogenously and Electrically Welded Boilers and Containers" by Mr. E. Hohn, published in the June, 1926, issue of the JOURNAL of the American Welding Society, was translated from *Zeitschrift des Vereines deutscher Ingenieure* by *Mechanical Engineering*. The cuts were also loaned through the courtesy of the A. S. M. E.

SECTION ACTIVITIES

Los Angeles

The June meeting of the Section will be held on the 24th, at which time Mr. Casad, Shell Oil Company, will talk on pipe-line welding.

Western New York

The regular meeting of the Section was held on May 26. The time was selected to fit in with the Master Boiler Makers Association Convention, which was held in Buffalo on May 25 to 28. Mr. S. W. Miller presented a paper on "Essentials in Fusion Welding." The following offiers were elected to serve for the coming year: Robert Siemer, Chairman; R. E. Kinkead, Vice-Chairman; Carl D. Miller, Secretary and Treasurer; G. W. Swan, representative to the Board of Directors, American Welding Society. On the Executive Committee for two-year term: Robert Siemer, R. E. Kinkead, Carl D. Miller and G. W. Swan; for one-year term: P. W. Kromer, George Neher, J. H. Sander and C. B. Davison.

A report of the standing committee on welding of the Master Boiler Makers Association recommended the removal of many restrictions on welding in railroad shops, which automatically increases the field of fusion welding.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to Society headquarters.*

POSITIONS VACANT

V-34. Want to secure an acetylene welder who is proficient in the art of welding holes in defective cast iron castings. Position is a steady one.

SERVICES AVAILABLE

A-48. Welder desires position. Have had four years' experience in boiler and tank work. Can also weld cast iron and high pressure work.

A-49. Electric welder desires position. Have had all around experience, including several years with Lackawanna Railroad, and have also had arc, spot and gas welding experience with R. Hoe & Company and Siemund Wenzel Company.

YEAR BOOK

The next issue of the Journal will be devoted exclusively to a Year Book of the Society, including full information as to Society activities, constitution and by-laws, work of the American Bureau of Welding, personnel of research committees of the Bureau, an alphabetical list of members of the Society and geographical list of members, description of the supporting members of the Society and an advertising section. Extra Copies will be furnished any member upon request for solicitation of new members.

COMMITTEE ON WELDED RAIL JOINTS

Progress Report No. 4—July, 1926

A summary of Tests and Reports Since Progress Report No. 3—April, 1925

Organization:

The American Electric Railway Association and the American Bureau of Welding* united in an authoritative investigation of various types of welded rail joints in commercial use through a thoroughly representative committee which was organized late in 1921. This committee has a membership of about sixty individuals, including Way Engineers of several of the larger street railway companies, representatives of manufacturers of welded joints and welding equipment, welding experts, scientists and testing experts.

Dr. G. K. Burgess, then head of the division of Metallurgy, Bureau of Standards, and now Director of the Bureau of Standards, was elected as chairman. E. M. T. Ryder, Way Engineer of the Third Avenue Railway System, was elected vice-chairman and W. Spraragen, secretary of the Division of Engineering and the American Bureau of Welding, was appointed executive secretary. Inasmuch as it was impossible to have this large committee meet more than once or twice a year, the administration of the affairs of the committee was left in the hands of a small representative Executive Committee.

Relation of American Electric Railway Engineering Association:

About $24,000 was contributed by the American Electric Railway Association, interested manufacturers, and a number of the larger street railways. The Association is acting as treasurer for the funds. Expenditures are made upon authorization of the Executive Committee and the bills are countersigned by the secretary and the vice-chairman of the committee and by a member of the Executive Committee of the American Electric Railway Engineering Association.

Objects:

The primary object of the committee is to improve each type of welded rail joint rather than to make comparative tests on the relative merits of the different types of joints.

Progress Report No. 1:

In order to compile a summary of the "present state of the art," a questionnaire was prepared on five types of welded joints in commercial use (cast, butt, bar, electric seam and thermit) and

*The Bureau is the welding research department of the American Welding Society and the Division of Engineering, National Research Council.

members of the committee were circularized. Answers to the questionnaire were correlated and a progress report of 73 pages printed in May, 1922. Typical problems needing further investigation were also included in the report.

Preliminary Program:

It was agreed that the next step was to test out joints representing the "present state of the art" by testing joints of each type made by representative street railways companies and by the manufacturers. Tensile, drop, repeated impact, bend and conductivity tests were made on each type of joint. In order to distribute the work the Bureau of Standards made the conductivity, repeated impact and tensile tests and also metallurgical examinations. Purdue University made the bend and conductivity tests and the University of Illinois the drop tests.

Progress Report No. 2:

Progress Report No. 2 was published by the committee in March, 1924. It consists of seventy-two printed pages and includes information on the organization of the committee; instructions issued to railway companies for making up test joints for the committee; methods of procedure and results in making tensile, bend, drop and conductivity tests; data furnished by the makers of these joints; photographs of specimens broken by the various tests and the discussion of the report.

Progress Report No. 3:

The Third Progress Report of the Committee on Welded Rail Joints, published April, 1925, does not include any of the results previously reported in Progress Report No. 2. It contains findings of the committee, test data and other material of interest to the committee obtained since the publication of Progress Report No. 2. Specifically it includes the remainder of results on tensile, bending and drop tests made on specimens to determine the present state of the art. The first results obtained from the repeated impact testing machine, as well as preliminary tests on the telemeter, are recorded in the report. In addition, there is also included the report of the joint examination sub-committee which carefully examined macroscopically and microscopically broken specimens; and the report of the sub-committee on Development whose function it was to draw up a program to test out the variables which affect the quality of the seam welded type of joint.

Progress Report No. 4:

This is the Fourth Progress Report of the Committee on Welded Rail Joints. It does not include any of the results previously reported in Progress Reports 2 and 3. The report is devoted exclusively to the test data and findings of the committee in connection with the repeated impact tests made to determine the present state

of the art. As in previous instances, no attempt has been made to formulate conclusions at this time. The report also includes discussions by individual members of Progress Report No. 3. These discussions are signed and the committee takes no responsibility for the opinions expressed by such individuals.

Repeated Impact Tests of Welded Rail Joints

An outline of the reasons for making repeated impact tests of welded rail joints, an account of the steps in the design and development of the machine now in use, and a discussion of the methods for supporting and testing the rail joints have been published in Progress Report No. 3 (issued in April, 1925), Committee on Welded Rail Joints, page 38. The method of making up the joints is described in Progress Report No. 2, issued in March, 1924.

The joints for this series of tests were made up by various electric railway companies and manufacturers to illustrate the types of joints in general use at the time when the Committee on Welded Rail Joints began its program looking toward the improvement of the various types of welded rail joints.

The joints furnished by the various street railway companies to represent "The Present State of the Art" have been tested and the results of the individual tests are given in the seven charts shown in Progress Report No. 4, pages 10 to 16. Sixty-six rail joints and four solid rails have been tested.

The rail used in all cases was A. E. R. E. A. Standard 7-in. girder rail rolled under A. E. R. E. A. specification W-1-23, Class "B". Part of it was contributed by the Bethlehem Steel Company and part by the Lorain Steel Company.

In all of these tests the span was 22 in. and the hammer struck the rail at the middle of the span and 2in. from the center of the joint. The hammer weighed 400 lb. and dropped 6 in. (energy of blow 200 ft.-lb.) at a rate of about 70 blows per minute.

The anvil to which the supports for the specimen were attached weighed 16,000 lb. and rested upon helical springs. Its vibration was damped so that it came to rest after each blow before the next was struck.

During the tests a record was kept of the development of cracks in the specimens. These failure charts are given in this report.

Charts Showing Progressive Failure of Joints Under Repeated Impact Tests

In order to summarize test data showing the progress of the failure of the joints under the repeated impact test in convenient form, this information has been arranged on charts which follow.

There appears on the charts reference notes in connection with a few joints in which the reader is referred to the text. The remarks with reference to these joints are as follows:

14-6. The crank shown in dotted lines, letter "L", extended in the

groove of the rail from the joint to a point right opposite the tup.

15-12. At 142,100 blows a crack developed in the base of the rail over the right-hand knife-edge support as viewed from the lip side. At 147,100 blows a crack developed under the tup running longitudinally in the head of the rail to the joint.

15-14. At about 158,000 blows a crack developed under the tup running longitudinally in the head of the rail to the joint.

15-30. A crack developed under the tup in this specimen and the fused metal in the seam adjacent to it bent, but did not crack.

15-36. At about 214,300 blows a piece of the head of the rail broke out, the crack running diagonally under the tup to a point 6 in. away from the joint.

Photographs of Broken Specimens

Typical photographs showing the methods of failure of each type of joint are reproduced in the following pages of this report. In order to save space representative photographs were selected and a notation made in the caption to indicate those joints which failed in a similar way.

KEY TO TEST SPECIMENS

Test Joint Schedule No. 1

Type of Joint	Made by	Steel from	Joint Numbers
Cast Iron	Cram	Bethlehem	3- 1 to 3-12
Cast Iron	Pinckley	Bethlehem	13- 1 to 13-12
Cast Iron	Wilson	Lorain	18- 1 to 18-12
Bar Weld	George	Lorain	6- 1 to 6-24
Butt Weld	Lorain	Lorain	11-13 to 11-24
Butt Weld	Lorain	Bethlehem	11-25 to 11-36
Seam Weld			
Carbon Electrode	Clark	Bethlehem	2- 1 to 2-12
Carbon Electrode	Dalgleish	Bethlehem	4- 1 to 4-12
Carbon Electrode	Estill	Bethlehem	5- 1 to 5-12
Carbon Electrode	Graves	Lorain	8- 1 to 8-12
Carbon Electrode	R. W. & B. Co.	Lorain	14- 1 to 14-12
Carbon Electrode	Ryder	Lorain	15- 1 to 15-12
Carbon Electrode	Ryder	Lorain	15-25 to 15-36
Carbon Electrode	Steward	Bethlehem	16- 1 to 16-12
Carbon Electrode	Wysor	Bethlehem	21- 1 to 21-12
Seam Weld			
Metallic Electrode	Gould	Bethlehem	7- 1 to 7-12
Metallic Electrode	Lincoln	Lorain	25- 1 to 25-12
Apex Type	Way	Bethlehem	22- 1 to 22-12
Apex Type	Ind. S. & F. Co.	Bethlehem	9- 1 to 9-12
Thermit Weld	M. & T. Corp.	Lorain	12- 1 to 12-12
Thermit Weld	Ryder	Lorain	15-13 to 15-24

REPEATED IMPACT TESTS

The test results shown on the following diagrams comprise the complete set of repeated impact tests made by the U. S. Bureau of Standards on the so-called state of the art series on welded rail joints. The following facts should be borne in mind in studying the diagrams:

The Bureau of Standards kept a graphical record of the progressive failure of each joint. The speed of testing was about seventy blows per minute and observations were made at not longer than one hour intervals and more frequently if found necessary. The total number of blows to which a joint was subjected was generally far beyond the number necessary to destroy the joint for practical purposes, so that the total number of blows given to a joint should not be considered as any indication of its ability to resist repeated impact stresses or of its practical or commercial value as a joint.

In a number of cases there were more observations reported than are shown on the diagrams where, for convenience, a number of observations showing short cracks have been consolidated under a single letter, especially where the number of blows since the preceding record point was small and where the total number of blows was large. No such consolidation, however, was made for the first six or eight cracks recorded, as it was felt that these first cracks were the most important, showing the ability of the joint to resist impact without serious failure and, therefore, the early records are given in full.

"A Key to Test Specimens" showing which rail is used and by whom the joints were made is shown on page 9. A brief description of the diagrams is given below and is, for convenience, repeated on page 12 and 14.

"Description of Diagram"

For each pair of sketches upper view shows head side and lower view lip side of joints tested as indicated by letters "H" and "L" respectively where shown. Of numbers connected by dash, such as 2-14, the first number indicates the maker of joint and the second number the serial number in that series. Letters in alphabetical order indicate cracks occuring with corresponding number of blows. Location and dimension of cracks are shown approximately to scale.

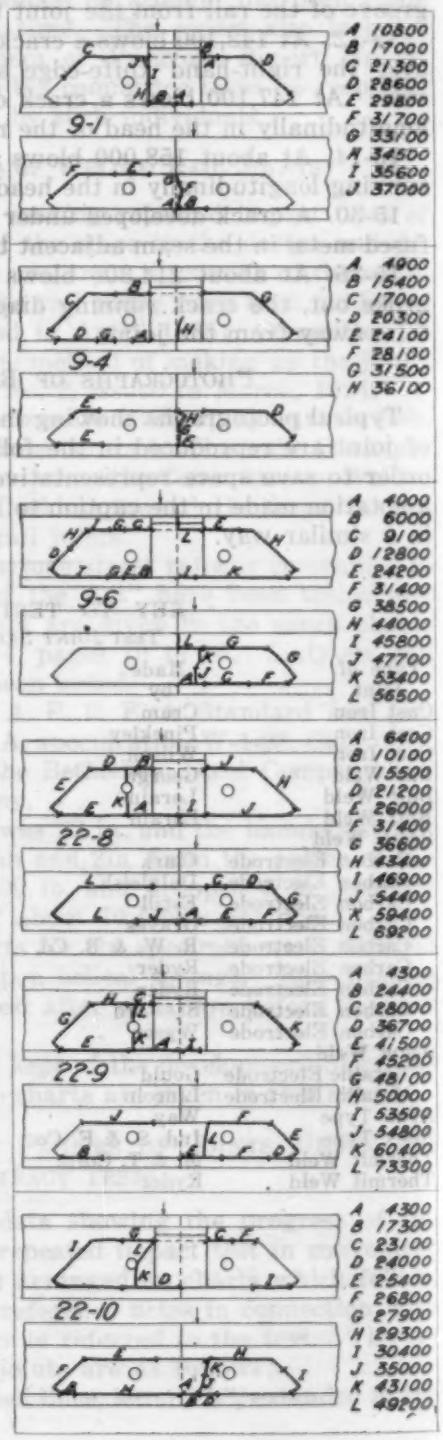


Fig. 1. Apex Welded Joints

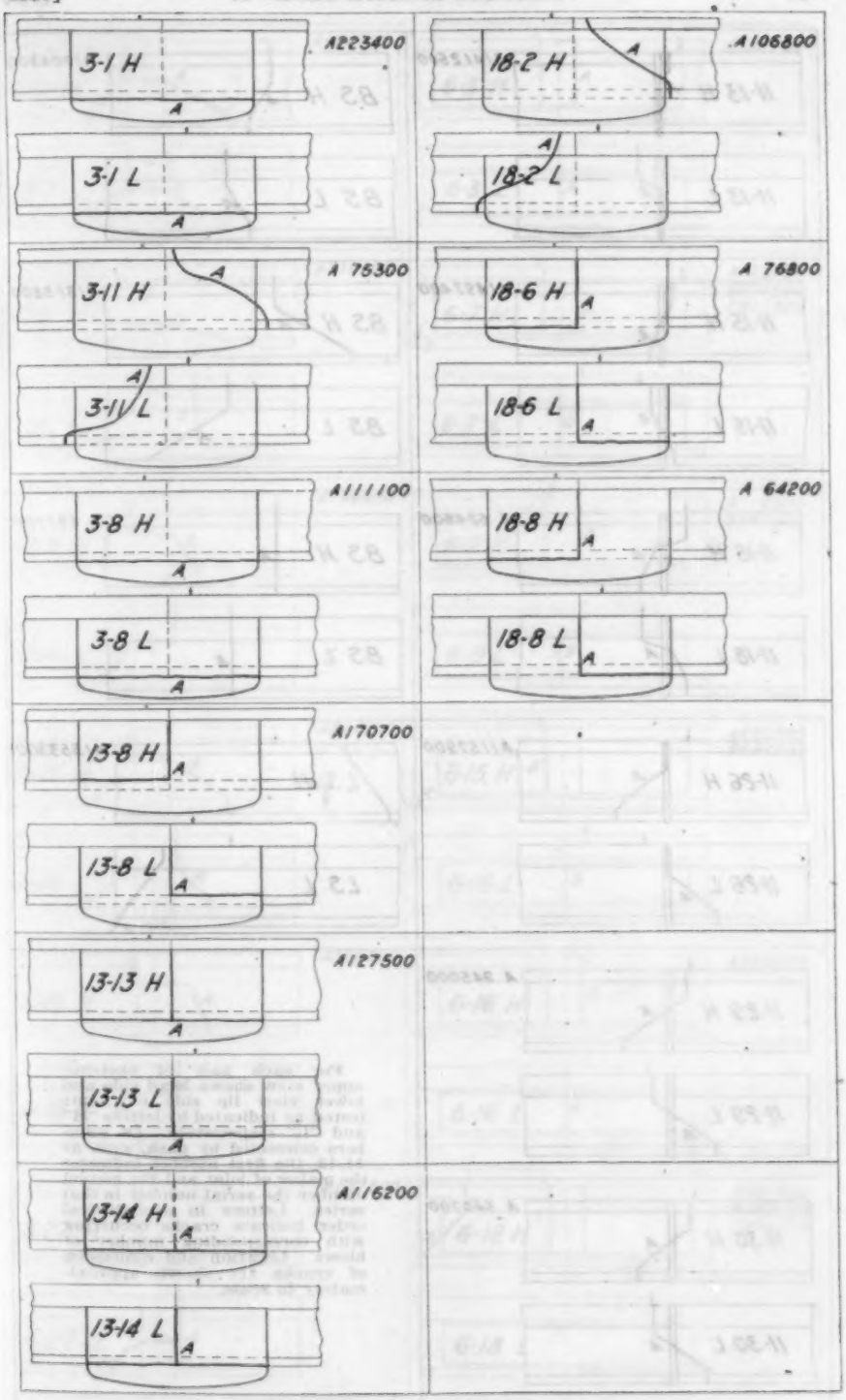
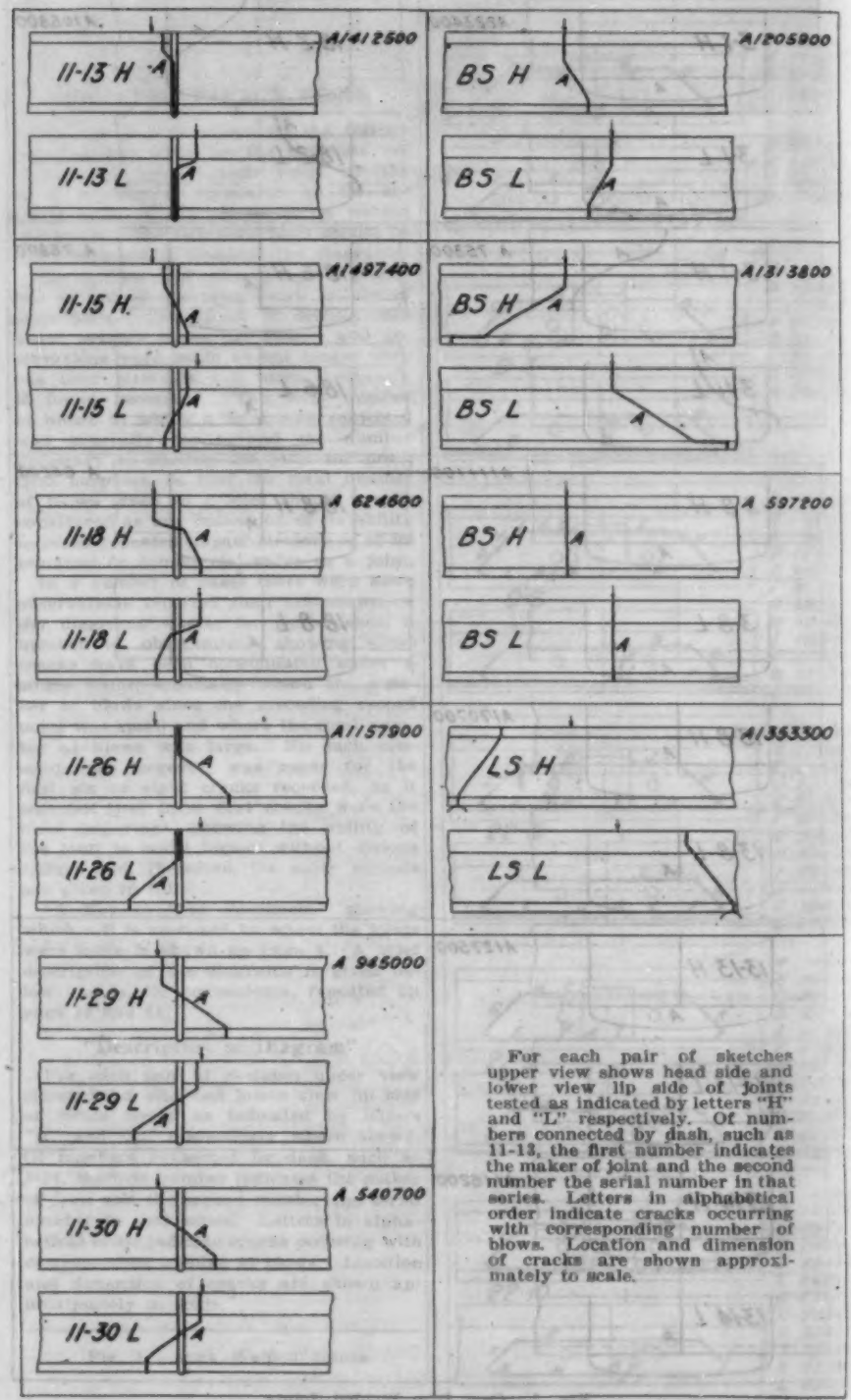
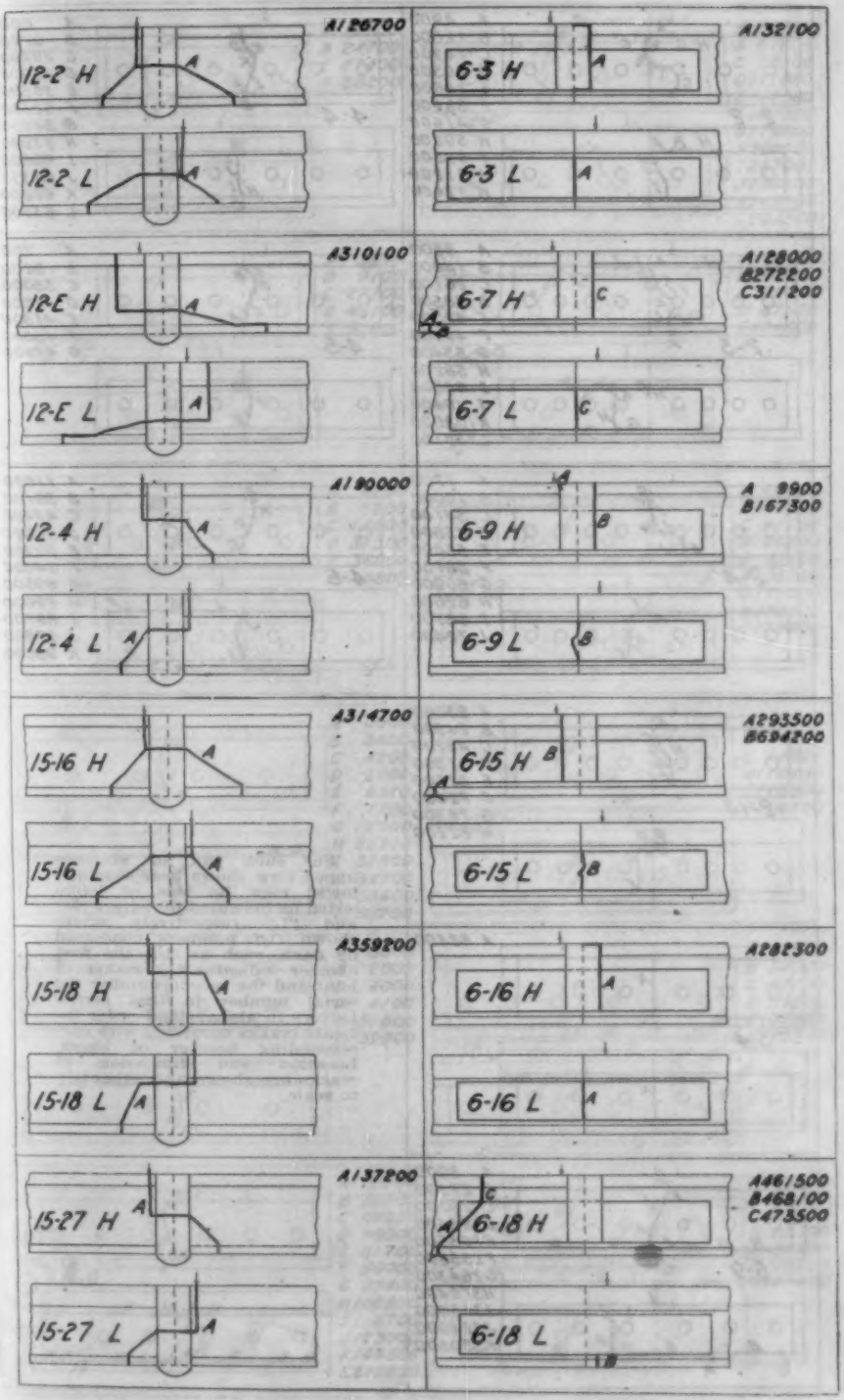


Fig. 2. Cast Iron Welded Joints



Butt Welded Joints — Unbroken Rails

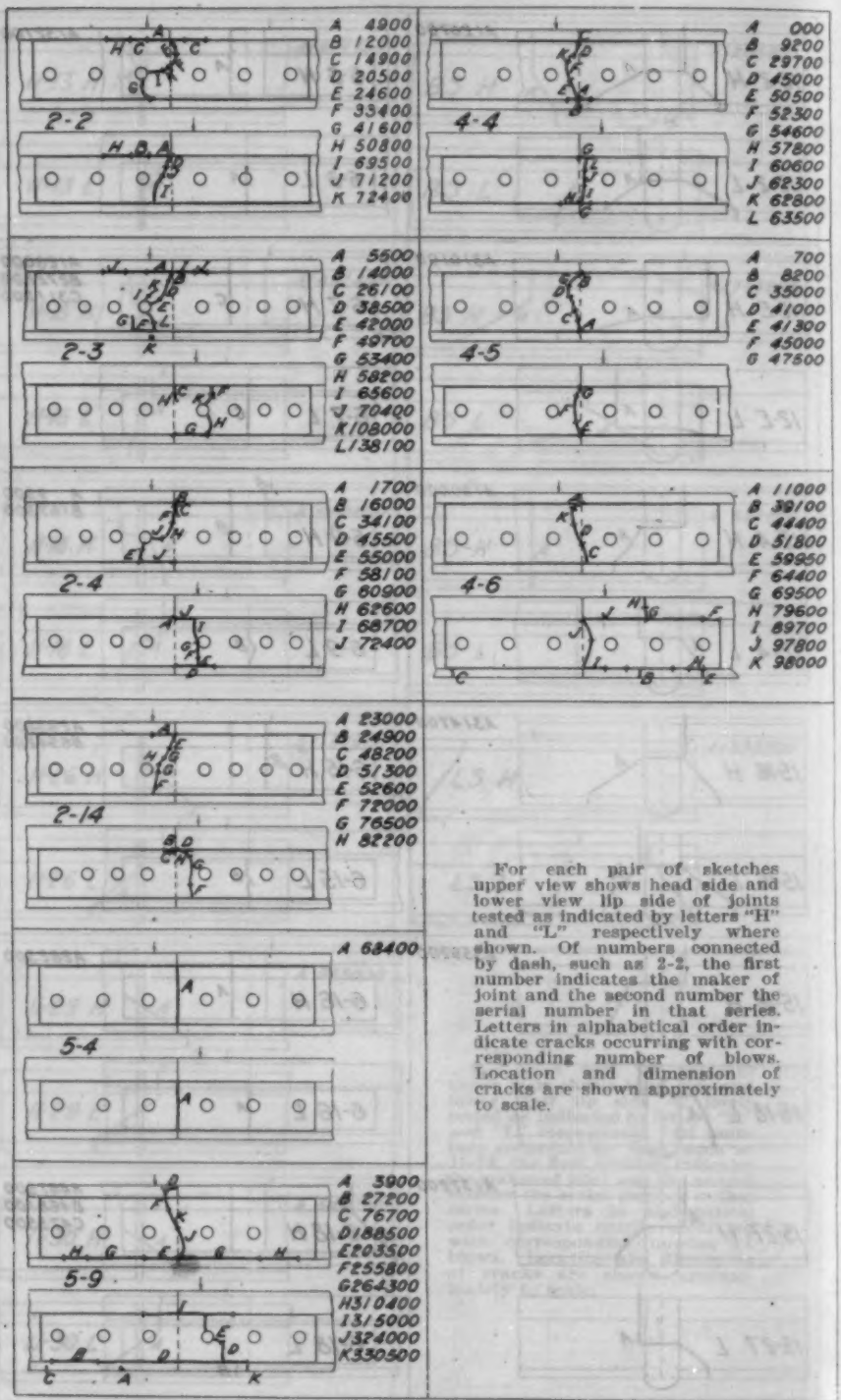
Fig. 3



Thermit Welded Joints

Bar Welded Joints

Fig. 4



For each pair of sketches upper view shows head side and lower view lip side of joints tested as indicated by letters "H" and "L" respectively where shown. Of numbers connected by dash, such as 2-2, the first number indicates the maker of joint and the second number the serial number in that series. Letters in alphabetical order indicate cracks occurring with corresponding number of blows. Location and dimension of cracks are shown approximately to scale.

Fig. 5. Seam Welded Joints

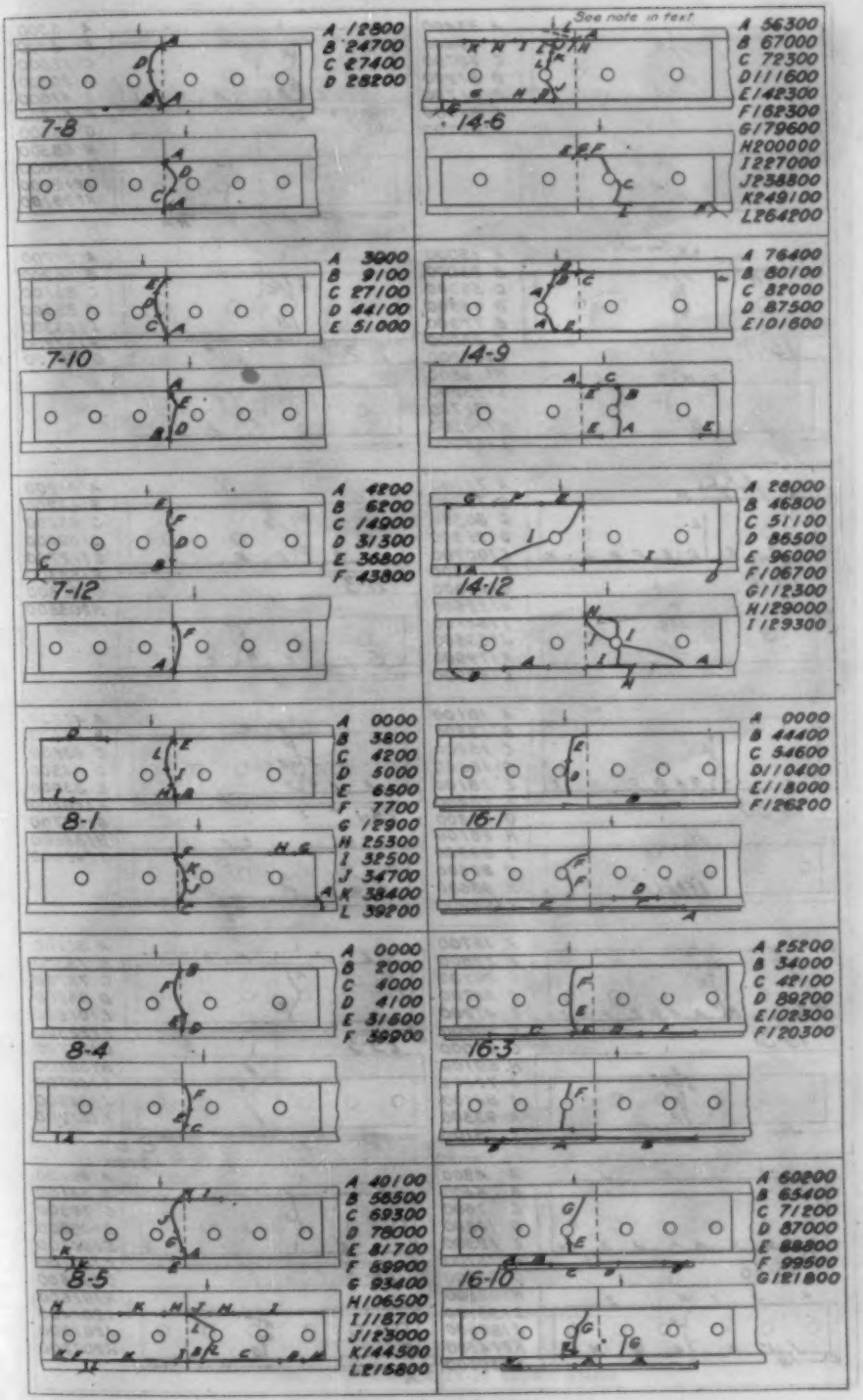


Fig. 6. Seam Welded Joints

Fig. 7. Seam Welded Joints

Fig. 8. Upper two figures are specimens of solid rail. Lower three are butt welds. Break in solid rail "A" similar to that in "C" shown above. Break in butt joints 11-29, 11-30 similar to that of 11-26 shown above

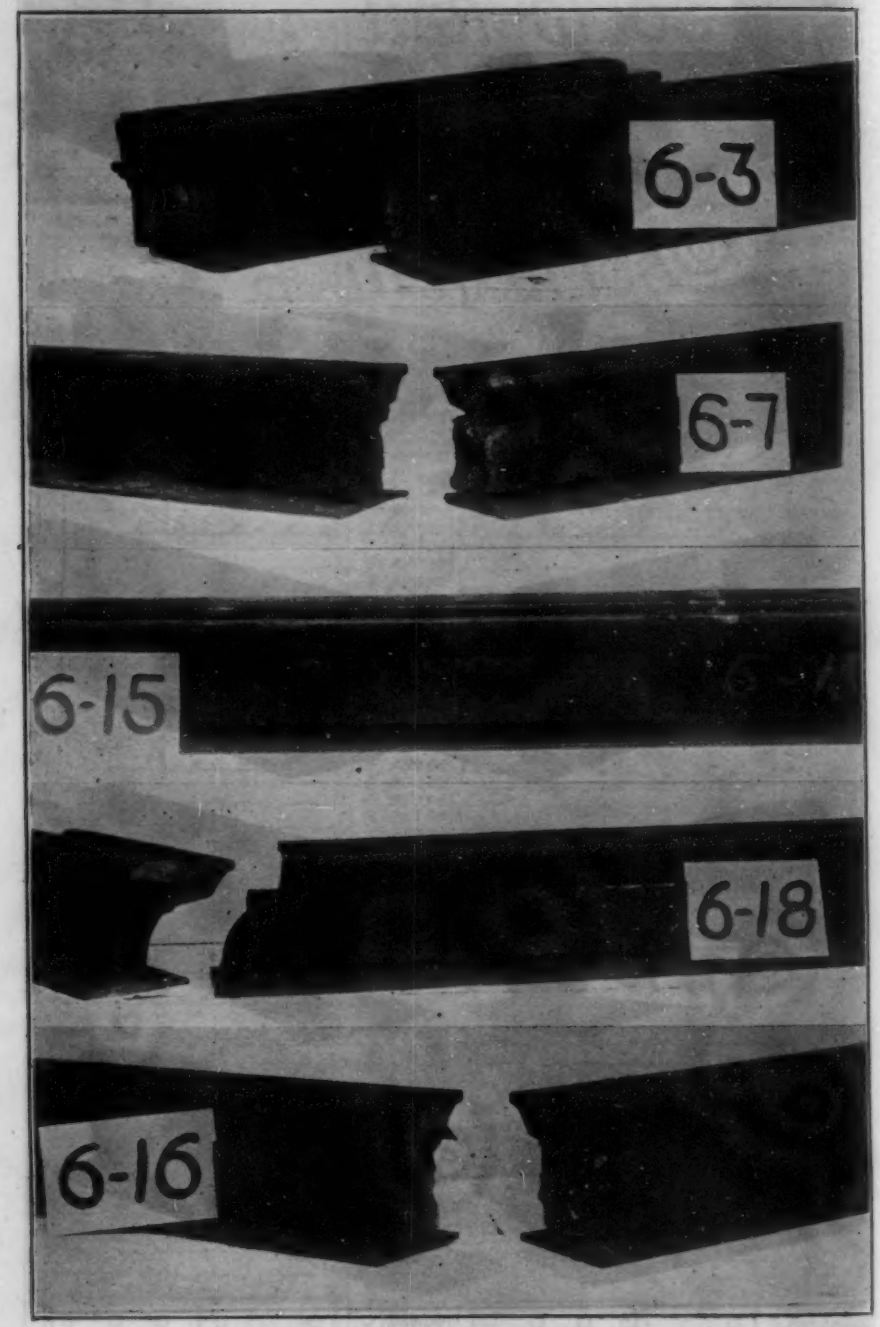


Fig. 9. Bar Joints. Break in specimen 6-9 similar to that of 6-16 shown above

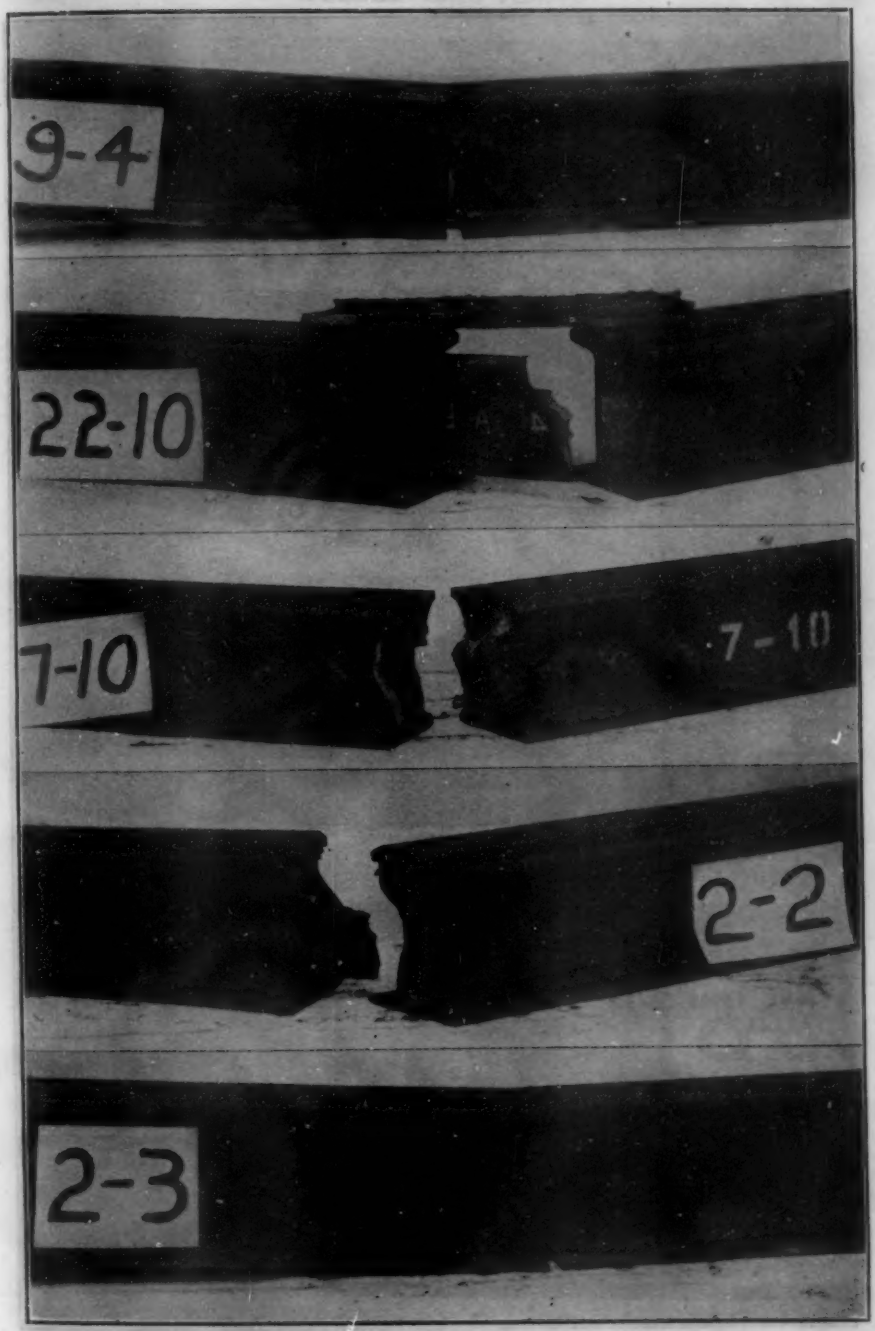


Fig. 10. Upper two figures "Apex" welds, lower three, "Seam" welds. Break in specimen 9-1 was similar to that of 9-4 except the plate broke at the edge of the head support instead of the center. Break in 9-6, 22-8, and 22-9 similar to that of 22-10 shown above. Break in 7-8, 7-12, similar to that of 7-10 shown above. Breaks in 2-4 and 2-14 similar to that of 2-3

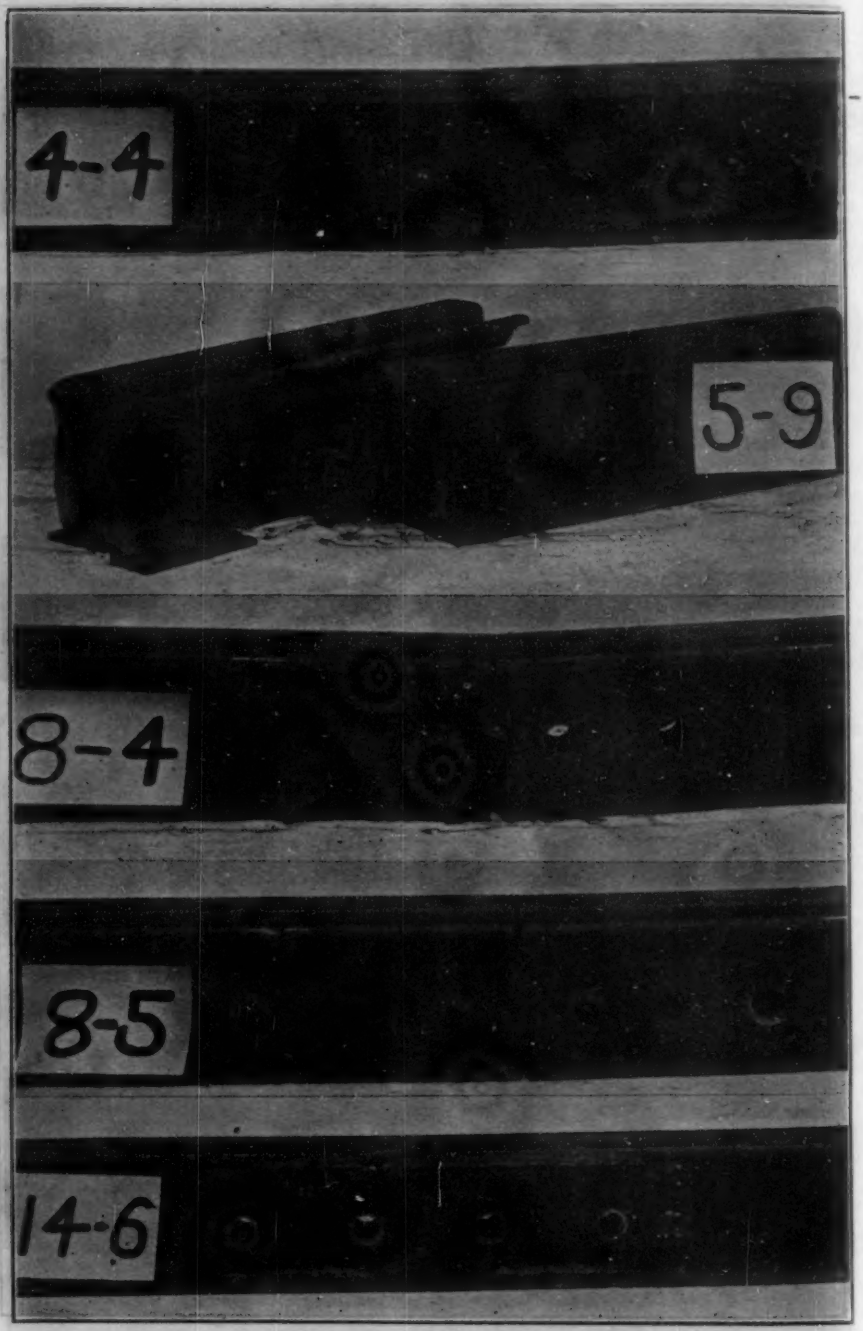


Fig. 11. Seam Welds. Breaks in specimens 4-5 and 4-6 similar to that of 4-4 shown above. Break in 8-1 similar to that of 8-4. Breaks in specimen 14-9 similar to that in 14-6

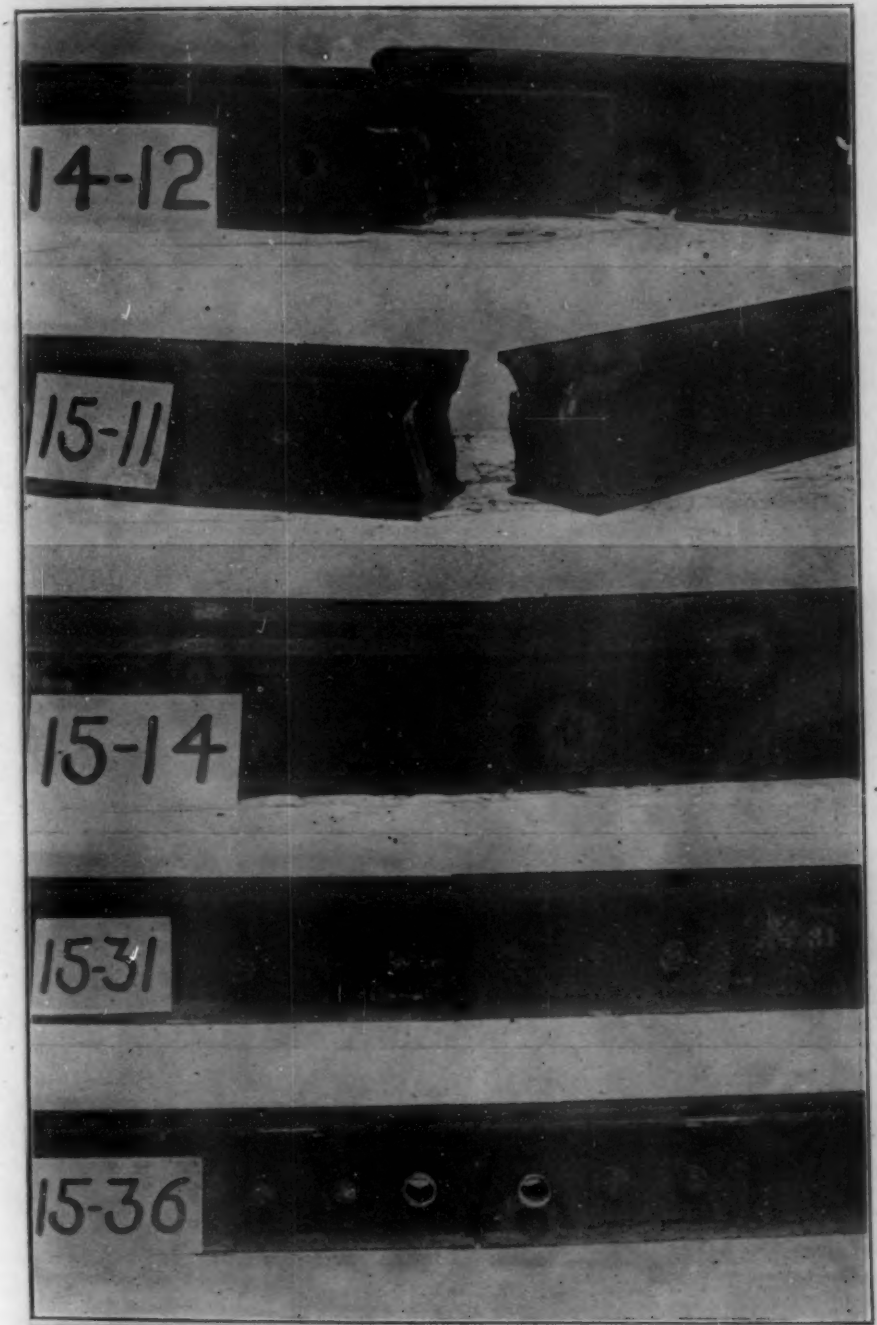


Fig. 12. Seam Welds. Break in 15-12 similar to that of 15-11. Break in 15-30 similar to that of 15-14 shown above

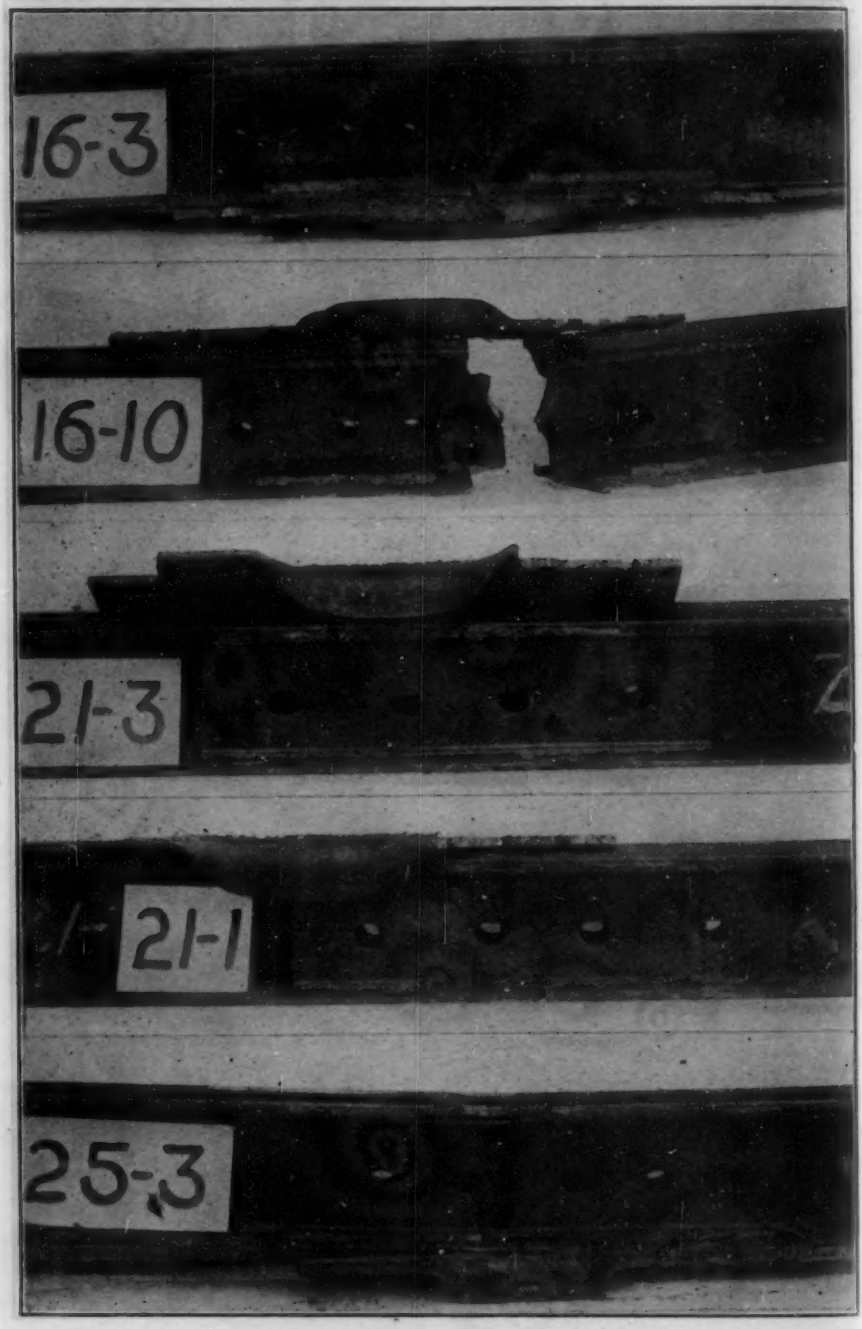


Fig. 13. Seam Welds with Base Plate. Break in 16-1 similar to that of 16-3. Break in 21-2 similar to that of 21-1. Break in 25-1 and 25-4 similar to that of 25-3

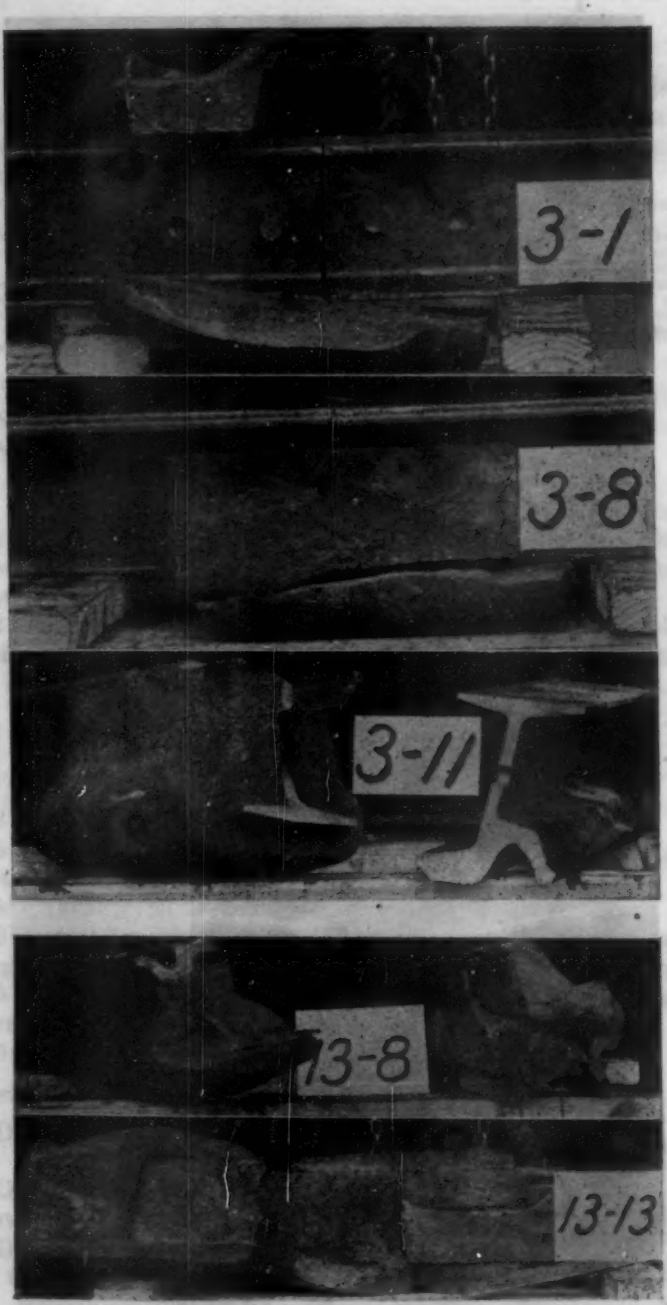


Fig. 14. Cast Iron Joints. Break in joint 13-14 similar to that of 13-13 shown above

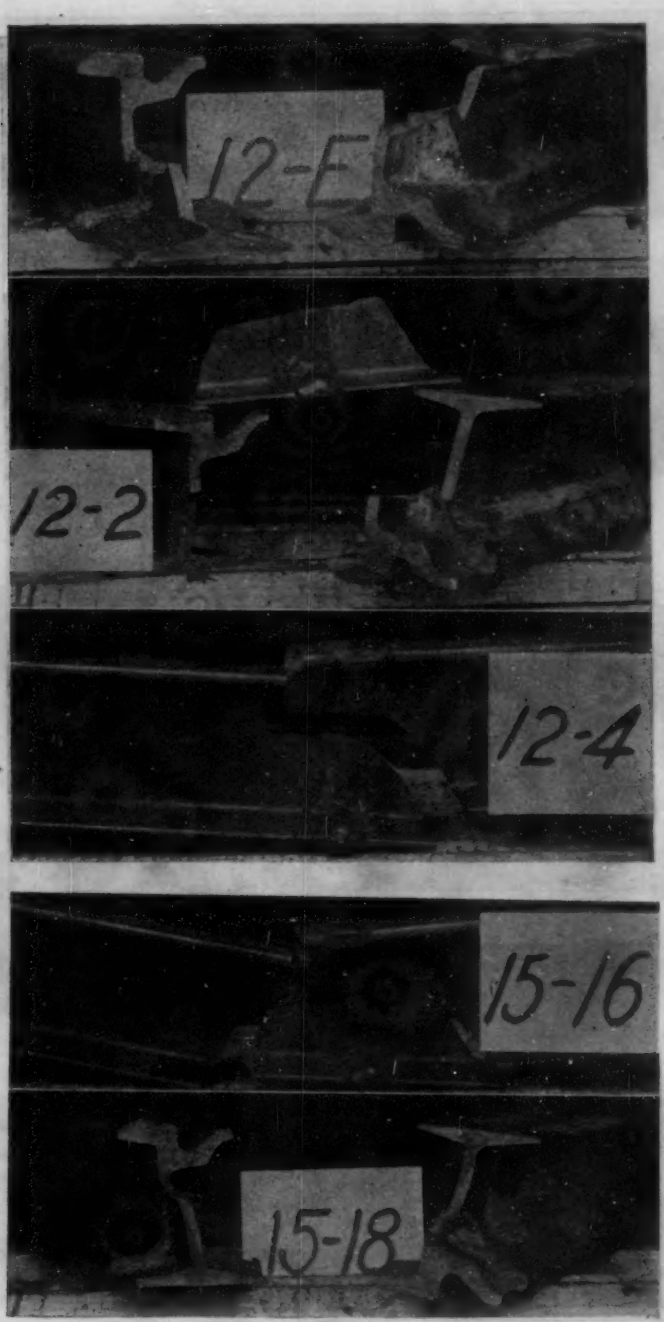


Fig. 15. Thermit Joints. Break in 15-27 same as 15-18 shown above

Report of Sub-Committee on Inspection of Fractured Joints

This report is not given in the same detail as those published in previous reports. Only such information has been included as is not clearly brought out by the photographs of the broken joints or by the charts showing progressive failure of each joint.

Note by S. W. Miller: In the following report "Detail" is used to denote progressive fractures. Mr. Miller states:
"Fatigue," "Detail" or "Progressive" fractures are caused by a service fiber stress that is too high, so that the steel may be said to be fatigued—"Detail" and "Progressive" describe the action—the piece is not broken all at once, but a little at a time. The appearance of the fracture is characteristic, some being worn smooth by rubbing of the parts together, the best being rough, where the section has not been large enough to stand the stress and so was ruptured suddenly. Another evidence is the lack of elongation at the break. The common shop terms are "old break" or "crystallized" metal.

Cast Iron Welds

3-1 No special remarks.

3-8 No special remarks.

3-11 No special remarks.

13-8 Fracture in base of rail smooth. Probably detail fracture.

13-13 Both ends of rail burned away by hot metal. One end rail base broke on lip side at root of web from joint to end of casting showing detail fracture.

13-14 Sheared at bottom of base of casting. Casting cold shut on outside. Part of base of rail near joint melted away by casting.

18-2 Detail fracture at hole.

18-6 No special remarks.

18-8 No special remarks.

Butt Welds

11-13 No special remarks.

11-15 Two detail fractures, one at top of web and other at center about ¾ in. above base.

11-18 Characteristic fracture.

11-26 Detail fracture is shown beginning at top of web and going diagonally 3½ in. Rest of fracture in web and base granular.

11-29 Detail fracture 4 in. long in web. Fracture in head and base granular.

11-30 Detail fracture 2 in. long in web.

Bar Welds

6-3 Detail fracture both plates at head side close to one end of chuck. Metal seems to have been hot 2 in. from joint.

6-7 Detail fracture at bottom on both sides. Metal seems to be badly overheated.

6-9 Detail fracture at bottom of plates.

6-15 Chuck pulled loose from bar under head and from head of rail.

6-16 Detail fracture top and bottom of plates.

6-18 Detail fracture from base to top of web. Some evidence of detail fracture at outer edge of lip.

Seam Welds

2-2 Detail fractures top and bottom both side plates.

2-3 Seam welds not damaged.

2-4 Seam welds not damaged.

2-14 Detail fracture top and bottom of plate. Seams not damaged.

4-4 Detail fracture at bottom of plates. Seam welds not damaged.

4-5 Detail fracture at bottom both joint plates. Seam welds not damaged.

4-6 Detail fracture top and bottom both plates.

5-4 Detail fracture in both plates under lip for entire surface under head, top and bottom. Seam welds not damaged.

5-9 Plates show detail fracture top and bottom.

7-8 Plates broke through joint top and bottom. Detail fracture. Seam welds not damaged.

7-10 Detail fracture in plates top, both sides. Seam welds run around ends of plate on base. No defects in seam welds. Base welds unusually heavy.

7-12 Plates broke through joint both sides, with detail fractures. Seam welds not damaged.

8-1 Top of both plates show detail fractures. No fracture in seam welds.

8-4 Detail fracture at bottom of plates both sides. Seam welds not damaged.

8-5 Detail fracture in plate top and bottom head side, bottom lip side. Top seam showed no fusion for 9 in. to plate. Bottom not fused for 3 in. to base.

14-6 Detail fracture in plates top and bottom.

14-9 No special remarks.

14-12 Plate on head side broke loose through weld same end as fracture. No distortion of plate.

15-11 Detail fractures at top and bottom of plates both sides. Seam welds not damaged.

15-12 Detail fracture in plates top and bottom and both sides.

15-14 Detail fracture bottom lip side plate.

15-30 No special remarks.

15-31 Detail fracture in plates.

15-36 All welds sheared full length.

16-1 No special remarks.

16-3 Base plates loose. Not welded to base. Penetration in base plate fillet not good.

16-10 Base plates entirely loose.

21-1 Base plates broke loose.

21-2 Base plate broke loose.

21-3 Base plates broke loose.

25-1 No special remarks.

25-3 No special remarks.

25-4 No special remarks.

Apex Joints

9-1 No special remarks.

9-4 No special remarks.

9-6 Poor fusion in many places.

22-8 All welds loose.

22-9 One plate completely loose.

22-10 Bottom plates loose from base in several places, lip and head side.

Thermit Welds

12-E Characteristic type of fracture.

12-2 Shear in center of web shows detail fracture. Rest granular.

12-4 Same as 12-2.

15-16 Shear in center of web seems to be detail fracture; rest granular.

15-18 Same as 15-16.

15-27 Same as 15-16.

Solid Rails

A Detail fracture under web nucleus at slight lap in base.

B Detail fracture entirely through base 3 in. along junction of web and base. Rest of fracture granular.

C Detail fracture under web nucleus at slight lap in base.

Bureau of Standards Progress Report No. 16

To Members of the Executive Committee on Welded Rail Joints on Tensile Tests, Chemical Analyses and Metallographic Examinations on Solid Bethlehem Rails

Metallographic examinations, tensile tests and chemical analyses have been carried out at the Bureau of Standards on the solid Bethlehem rails 11739B and 11739C and strain measurements have been made on the bar weld joint 6-18. These specimens had previously been tested in the repeated impact machine.

Tensile test specimens were cut from the center of the head, the center of the web and the center of the base of the solid Bethlehem rails. Chemical analysis of the material in the specimens was made after the tensile tests had been completed. The results of the tensile tests and chemical analyses are given in Table 1.

TABLE 1

Results of Tensile Tests and Chemical Analyses from Bethlehem Solid Rail Sections

Rail No.	Specimen from	Diameter, Inch	Proportional Limit, Lb./In.^{2}	Tensile Strength, Lb./In.^{2}	Elongation in 2 Inches, Per Cent	Reduct. of Area, Per Cent	Carbon Content, Per Cent	Phosphor Cont., Per Cent
11739B	Center of head	0.5055	31,000	126,200	12.0	15.4	0.73	0.029
11739B	Center of web	0.5055	48,000	129,700	13.0	20.0	0.72	.027
11739B	Center of base	.5058	55,000	129,200	13.0	17.2	0.75	.027
11739C	Center of head	.506	46,500	125,900	13.0	15.9	0.76	.028
11739C	Center of web	.488	37,500	133,500	14.0	18.7	0.78	.026
11739C	Center of base	.505	49,000	128,400	13.5	17.8	0.77	.029

No differences were found from the results of the tensile tests or chemical analyses that would account for the fact that rail 11739-B withstood 1,313,800 blows in the repeated impact machine while only 597,200 blows were required to break rail 11739-C.

The metallographic examination of these two rail sections is appended hereto.

"The Metallurgical Division states that while no differences were found in the two rails by microscopic or macroscopic examination

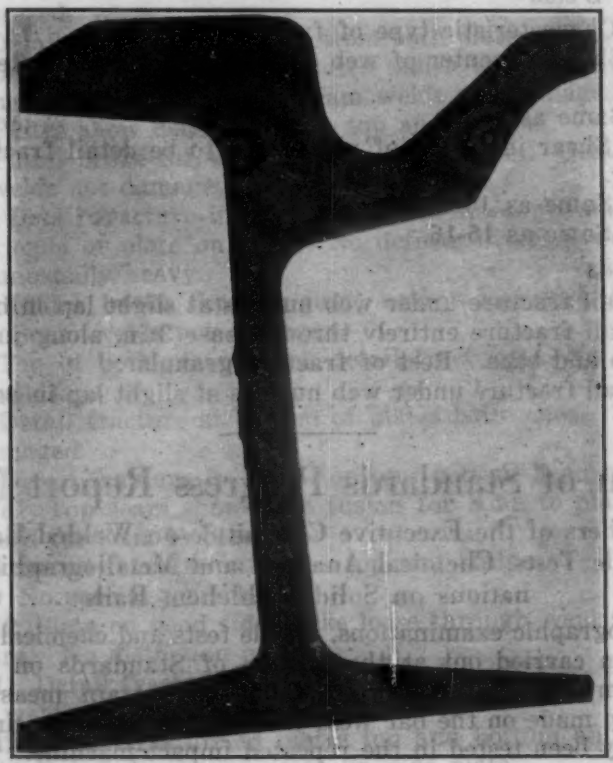


Fig. 16. Deeply Etched Cross Section of Bethlehem 11739-C Rail

that in any way account for the difference in number of blows endured, this comment should not be interpreted as carrying the idea that the slight streakiness and evidence of segregation has no effect upon endurance. We feel sure that it has, and that even the relatively few imhomogeneities noted in these rails are undesirable, could they be avoided. The *difference* in life may be due to undetectable differences in these inhomogeneities, but any difference is not sufficiently notable to be an acceptable explanation. Study of the effect of such inhomogeneities upon endurance of rail steel is highly desirable, but for such a purpose carefully machined test

bars and more refined methods of endurance testing would be required.

"In view of the very rough and ready nature of the impact test it is felt that the discrepancies noted in life are more probably due to the test than to the material, and the discrepancy is not large as discrepancies in endurance testing go any way.

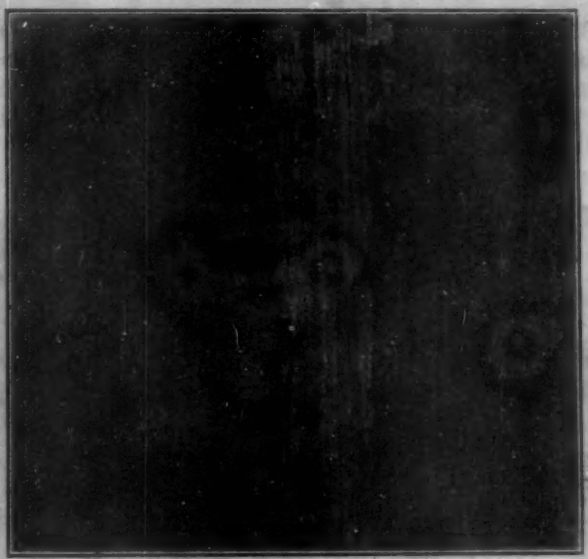


Fig. 17. Longitudinal Section through Base of Bethlehem 11,739-B Rail

The deeply etched cross-sections of the specimen shown above and also specimen 11739-C indicate a uniformly sound structure with no undue segregation. No traces of cracks or other mechanical flaws were detected in either rail. The longitudinal sections through the base showed some streakiness and slight segregation but no more than is to be expected in this type of material. There was no difference between the two rails in this respect.

Longitudinal sections through the head, web, and base of the two specimens were polished for microscopic examination. A survey of the number of inclusions showed the usual number and type of inclusions. As indicated by the appearance of the deep etched sections there was no pronounced segregation of sulphide inclusions in either sample. There was no noticeable difference between the two samples with respect to the number and type of inclusions.

The specimens were then etched with 2 per cent nitric acid in alcohol and examined. The structures in both were entirely similar, showing about the same grain size and rate of cooling. They were both of approximately eutectoid composition.

"Hence it is felt that analysis for oxygen content would hardly be justified."

Longitudinal strain readings were taken on bar weld joint 6-18 which withstood 473,500 blows in the repeated impact machine and then broke in the rail outside the bar. These measurements were made with a 2-in. Berry gage on both bars between the spot welds at mid-height on the bars. Readings were first taken on the bars in the condition in which they were after the repeated impact test.

Lines of holes 5 in. from the ends of each bar were then drilled transversely across the bars and another set of readings was taken. The four-gage lines extended from 5½ to 7½ in. from the ends of each bar and are believed to have been located between the end welds and the center welds. There was very little change in length in the gage lines before and after drilling the series of holes across the bars.

It might be expected that tensile stresses would exist in the bars after being welded to the plates and that the cutting would relieve these stresses and allow the gage lengths to become shorter. The readings, indicated, however, that three of the gage lengths increased slightly and there was no change in length in the fourth line. The results of these tests are given in Table 2. Stress is

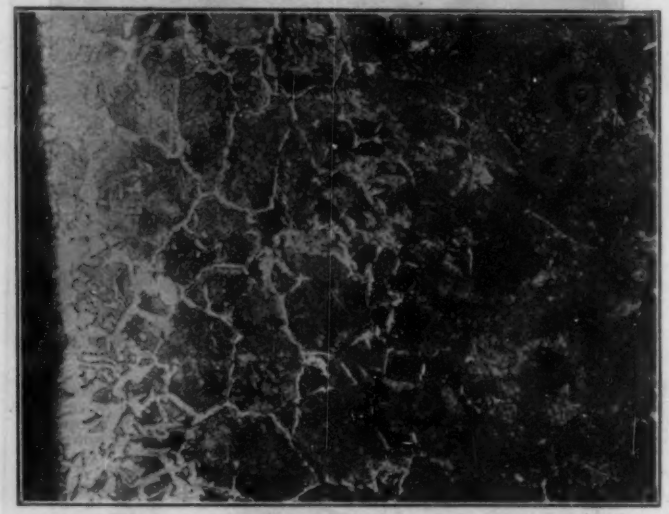


Fig. 18. Top of Head 11739-C Rail
The above micrograph shows the extent of the decarburized layer at the outer surface of the top of the head. The decarburization was about the same in both rails (11739-B and 11739-C).

computed from the strain on the assumption that the modulus of elasticity of the material in the bars was 29,000,000 lb./in.²

TABLE 2

STRAINS AND STRESSES IN THE BARS OF JOINT 6-18

Bar on	Gage Line on Bar Opposite	Strain, In./In.	Tensile Stress, Lb./In.²
Head side	Non-impact rail	0.000,000	0
Head side	Impact rail	.000,094	2,730
Lip side	Non-impact rail	.000,104	3,020
Lip side	Impact rail	.000,217	6,290

Metallographic Examination of Two Rail Specimens Tested in Repeated Impact Test

This report covers the metallographic examination of the 11739-B and 11739-C Bethlehem rails. The B rail had shown a

considerably longer endurance than the C rail. The examination was made to detect any mechanical or structural defects that might be present in the C rail, or any structural difference whatever between the two rails. The results of tension tests and of chemical analysis will be given in a subsequent report.

Fig. 19. Middle of Base, 11,739-B Rail

A cross-section of each rail about ½ in. from the fracture and a longitudinal section of each rail through the base, were deeply etched with hot concentrated hydrochloric acid. The following photographs approximately natural size, show the appearance of the etched sections. (*Editor's Note: Because of their similarity only typical photographs of each examination are shown.*)

In view of the *very* close similarity in the microstructure at corresponding points of the two rails, "gas analyses" of the two specimens were considered unnecessary and none was made. Summary:

The metallographic examination revealed no mechanical or structural defects in the C rail, nor any significant differences, either in macro- or microstructure, between the B and C Rails. The examination made indicates clearly that the low endurance of the C rail is not to be attributed to any special structural weakness such as could be determined in an examination of this kind, but rather that the low endurance is to be counted as one of the "erratic" results which are expected to occur in the type of test used.

Editor's Note: In the report of the Sub-Committee on Inspection of Fractured Joints published elsewhere in this report, there appears in connection with the "C" rail the statement "detail fracture under web nucleus at slight lap in base."

Discussions on Impact Testing

Memorandum by Dr. A. H. Stang, Bureau of Standards, Washington, D. C.

1. We have recently completed some interesting calculations on the effect of span-length upon stresses in 122-491 Trilby 7-in. rail under impact. These calculations are based upon the theory of "Inertia in Transverse Impact" as developed by Merriman in his "Mechanics of Materials" (Eleventh Edition, p. 334, et seq.). The weight of tup, height of fall and span lengths chosen for comparison are those in use by your committee at the Bureau of Standards, and by the Una Welding and Bonding Company, Cleveland, Ohio.

2. It is first assumed that the rails act as simple beams without end restraint and that all the energy of impact is used to stress the material in the rail between the supports. The calculations are as follows:

Quantity	Formula and Notation	Rail Joint Committee	U. W. & B. Co.
Weight of rail, lb./in.	$w = 122 \div 36$	3.39	3.39
Modulus of elasticity, lb./in.^{2}	E	30,000,000	30,000,000
Moment of inertia of rail, in.^{4}	I	77.66	77.66
Section modulus of rail, in.^{3}	I/c	20.06	20.06
Weight of tup, lb.	P	400	250
Span, in.	l	22	60
Weight of beam, lb.	W = wl	74.5	203.4
Height of drop, in.	h	6	10
Deflection under static load, in.	$f = \frac{Pl^3}{48EI}$	0.000038	0.000483
Stress due to static load, lb./in.^{2}	$S = \frac{Plc}{4I}$	110	187
Inertia coefficient	$n = \frac{1 + \frac{17W}{35P}}{\left(1 + \frac{5W}{8P}\right)^2}$	0.875	0.613
Stress due to impact, lb./in.^{2}	$T = S + S(1 + 2nh/f)^{1/2}$	57,900	29,900

3. If the rails are considered as beams with fixed ends, the calculated stresses due to impact are in both cases increased by about 28 per cent.

4. It is probable that the entire energy of impact is not used to stress the rail material in the tests at the Bureau of Standards, but that some of it is spent in accelerating the anvil and supports. This would have a similar effect to that of increasing the weight of the beam, W, and would therefore cause a decrease in the value of the inertia coefficient, n, and in the stress due to impact, T.

5. These theoretical calculations are called to your attention to show that increasing the span in transverse impact tests does not increase the impact stresses. The increased span leads to a larger

deflection under static load and the formula for stress due to impact, T, shows that f occurs in the denominator of one of the terms, the deflection increases as the cube of the span while the static stress increases only as the span, and, therefore, the impact stress will ordinarily decrease with increasing span.

6. We are bringing these computations to your attention as we believe that you are interested in comparison of the tests which your committee is making with impact tests made in other laboratories.

Discussion of Dr. Stang's Memorandum by R. B. Fehr, Development Engineer, Una Welding and Bonding Company.

1. The interesting communication from the Bureau of Standards on the subject of Impact Tests under date of Nov. 25 has been carefully studied and compared with similar calculations, based also on Merriman's treatment of the subject, which were made when we first started our repeated impact tests.

2. In studying the problem of transverse impact the writer has found it convenient and instructive to use an approximation of Merriman's equation. Using the same notation as in the Bureau of Standards' communication of Nov. 25, we have the following:

Let T = Stress due to transverse impact, lb./sq. in.

$$\text{Then: } T = S + S\left(1 + \frac{2nh}{f}\right)^{\frac{1}{2}} \qquad \text{(Merriman)}$$

3. Neglecting the first term, which is small compared with T, and neglecting the first term in parenthesis, which is also very small, and substituting for S and f, reducing and simplifying, we obtain the following expression for central transverse impact on simple beams:

$$T = 13{,}420\, c \left(\frac{Pnh}{Il}\right)^{\frac{1}{2}} \qquad \text{(Approx.)}$$

(When E = 30,000,000, as for steel.)

Where P = Weight of tup, lbs.
n = Inertia coefficient.
I = Moment of inertia of the beam, in.⁴
h = Height of drop, in.
l = Length of span, in.
c = Distance between the neutral axis and remotest fibre in tension, in.

4. By using the above approximate formula the values of 57,700 and 29,800 were obtained, instead of 57,900 and 29,900 respectively, as computed by Merriman's formula. The above approximate

formula has the advantage of showing at a glance what factors affect the stress due to impact. For example, the stress due to impact increases as the square root of the energy per blow, and inversely as the square root of the moment of inertia and the length of span, contrary to what is generally supposed. The above formula further indicates that the stress due to impact varies directly as distance c. In the case of fish plate joints it will thus be observed that the use of heavier fish plates will increase the moment of inertia (I) without changing appreciably the value of c, and should, therefore, decrease the stress T, other conditions being constant.

5. Another interesting point brought out by the above formula is that the calculated stress due to impact is practically independent of the relative load and height of drop as long as the product of these two factors is the same. It is true that the inertia coefficient is affected somewhat by the weight of the tup, but as this inertia coefficient varies from 0.6 in the extreme case of a 250-lb. tup to a value of nearly 1.0 in the case of an actual wheel load, and as the stress T varies only as the square root of the inertia coefficient, it is seen that this stress under practical conditions is practically constant when the product Ph is constant, other conditions being the same.

6. Of course, it is understood that the above formulas apply only for values of T below the elastic limit of the material. When the calculated stress exceeds the elastic limit of the material it is not to be expected that the actual stress will be even approximately equal to that of the calculated stress, but it is probably a safe assumption that the actual stress will likewise be above the elastic limit if the calculated value is above.

7. The writer has made a number of calculations of different combinations of factors. If anyone who is following these tests cares to go into this matter further, these figures will be gladly submitted.

8. This recent communication from the Bureau of Standards has called our attention to a point that is perhaps misunderstood by some who have been following the tests being made by the Welded Rail Joint Committee. We refer to the fact that some engineers apparently have not been clearly informed regarding our reasons for using a 60-in. span support in some of our recent tests, instead of the direct anvil support which had been used in all our previous tests, and also instead of the 22-in. span support which has been used by the Bureau of Standards. On page 129 of "Progress Report Number Three" of the Committee on Welded Rail Joints we made the following statement: "In order to determine the effects of pre-heating, post-heating, staggered plates, staggered seams, etc., as regards stresses in the rails, we have devised a means for holding joints 68 in. long on supports having a span of 60 in. It is recommended that further test joints be made of such

length (68 in.) that they can be tested on this wide span. The test will be a very severe one, but it will bring out in an accelerated degree the relative merits of pre-heating, post-heating, etc., as regards residual stresses in the rails."

9. In paragraph 3, item b, of our recommendations for the Boston Elevated test joint as recorded in our report dated July 17 (a copy of which, I understand, has been placed in your hands) the following statement occurs: "The total length of the joint should be 68 in. so that it can be tested in our new holding device, which is designed for the purpose of determining the effects of pre-heating, post-heating, staggered plates, staggered seams, etc." You will thus understand that our object in using a 60-in. span support instead of the 22-in. support as used by the Bureau of Standards, was to note the effects, if any, produced in the rails at the ends of the fish plates. Obviously a 22-in. support is not wide enough to cause any marked stresses due to impact in the rails at the ends of the fish plates.

10. The data which, it is hoped, will soon be obtained by means of the telemeter should enable engineers to make a better interpretation of the repeated impact test data. In the writer's opinion it is unfortunate that the conditions under which the repeated impact tests of the committee have been made were rather arbitrarily assumed. This statement is made with the definite knowledge of the fact that, while the energy of blow adopted in the committee test was based on the results of Mr. McIlraith's experiments in Philadelphia, the conditions of the rail support were not what Mr. McIlraith had in mind when he made his experiments for determining the energy of blow. The result is that, as pointed out by the writer at the meeting of the Committee on Welded Rail Joints held at Washington on Feb. 16, the severity of the repeated impact test was too great to give results that would be of any practical value. It is, therefore, of the highest importance that definite data be secured by means of the telemeter, so that the conditions of test (energy of blow, method of support, etc.) may be adjusted in such a way that the results will have practical value.

11. It seems to the writer that if, as has been frequently stated, "The primary object of the committee is to improve each type of welded rail joint rather than to make comparative tests on the relative merits of the different types of joints," it is absolutely essential that the committee determine as soon as possible what loads and stresses a given type of rail joint must meet in service, and then to determine as far as possible by carefully conducted tests under controlled conditions whether the given type of rail joint will meet the expected service conditions. Certainly no intelligent program for "improving each type of welded rail joint" can be followed unless some definite information is obtained as to the direction in which the improvement should take place. For example, if one is to be guided by the results of the recent repeated

impact tests made by the committee, he would try to improve the fatigue life of the fish plates in the case of some welded joints, and undoubtedly a considerable improvement could be effected along this line, at least as judged by the present method of testing. The danger, however, is that the present method of testing does not involve conditions sufficiently close to those obtained in practice to justify any conclusions that may be drawn from such tests. From a standpoint of engineering economics, it is important to know whether a given type of joint will fully meet *all* the conditions imposed upon it, and it is not so important to know whether it excels other types in a particular kind of test.

12. Now that a large amount of data has been obtained by the sub-committee on various types of joints and the advantages and disadvantages of the various methods of testing these joints, it should be possible to place the welded rail joint problem on a rational basis. In order to do this it is necessary that the following information be obtained:

A—Maximum stresses that occur in track under average operating conditions.

B—S-N diagrams (Unit stresses plotted against number of repetitions) of typical rail joints.

13. The following figure illustrates how the above information should be interpreted. The ordinates represent the unit stresses,

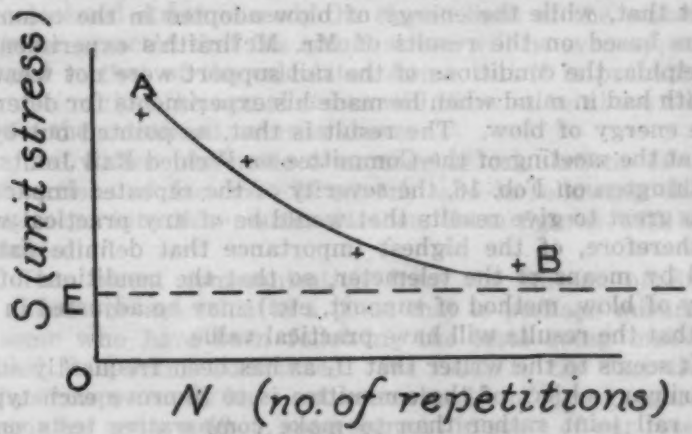


Fig. 20. S-N Diagram

which, of course, must be obtained by means of a telemeter for the various energies of blow that will be used in subsequent repeated impact tests. The abscissas represent the number of repetitions of the stress up to the point of failure. Curve A-B may thus represent the S-N diagram for a given type of joint. If the tests are carried far enough so that the asymtote EL of the curve AB is parallel to the horizontal axis, we can arrive at some fairly definite idea of the "endurance limit" of this particular type of rail joint. This "endurance limit" is thus represented by the unit

stress of the order of magnitude OE and represents that stress which can be repeated an indefinite number of times without causing fatigue failure.

14. Now, if the telemeter data that will have been obtained under average operating conditions indicate that in a given type of joint the maximum stresses are below the "endurance limit" as obtained from the S-N diagram shown above, we can be reasonably certain that that type of joint will have adequate fatigue life in service. In determining the maximum stresses that occur under average operating conditions, we must be sure to keep in mind the fact that to the stresses obtained by the telemeter must be added the stresses (as obtained by strain gage readings) due to the temperature changes. There may be some question as to whether we should obtain the maximum stresses that can occur under the worst conditions in service or whether we should, as suggested above, obtain merely the maximum stress under average operating conditions. In view of the fact that there is no danger involved in cases of welded rail joint failures (since these joints are in paved streets) it would seem that the better over-all economy in installation and maintenance can be obtained by aiming at the maximum stress under average operating conditions, rather than the maximum stress under unusual conditions.

15. Accordingly, we would suggest the following program to start with for the seam welded type of joint. Twelve rail joints (54 in. long) should be prepared under exactly the same conditions (preferably involving the latest improvements). Six of these joints should be set aside for repeated impact tests, using the leather pad support, while the other six should be set aside for smilar tests on the span support or modifications of the proposed leather pad support, etc. The following tests should be run, regular readings and complete data being secured as to the method of failure:

Joint No. 1—200 ft.-lb. per blow.
Joint No. 2— 50 ft.-lb. per blow.
Joint No. 3—100 ft.-lb. per blow.
Joints No. 4, 5 and 6—will then be tested under such conditions as may be dictated by a study of the above results.

16. It is understood, of course, that all of these repeated impact tests will be accompanied by sufficient telemeter data to enable us to arrive at a definite conclusion regarding the conditions of testing which will give stresses comparable to those that may be expected under average operating conditions. After the above preliminary work has been done we may find it possible to increase the severity of the test in order to save time in testing—but we must first make sure that an increased severity of test will give results showing the same order of merit that would be obtained under service conditions.

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Welding High Carbon Tool Steel and High Speed Steel with the Oxyacetylene Torch*

GEORGE L. WALKER†

The welding of high carbon tool steels and high-speed steels has an extensive field for development and one that has already met with considerable success. There yet remains a need for further study and development in methods and materials before these steels are as successfully and as extensively welded as are the lower carbon steels.

It is quite difficult to give a hard and fast rule for welding high-speed steels that will meet every demand. The piece that is to be welded, its design and purpose for which it is to be used as well as the chemical characteristics of the metal within the zone of welding, have an important influence on welding procedure. The experience of the welder also must be considered.

There are, however, some rules to be observed in welding these steels that are almost fundamental and which must be followed if any degree of success is to be realized.

High carbon tool steels are those steels containing from about 0.60 per cent carbon to 1.50 per cent carbon, and it is by reason of this high carbon content that they can be hardened and tempered and thereby serve in the cutting of metals.

High carbon tool steels are used principally in making tools of various kinds, such as milling cutters, drills, reamers, files, lathe tools, saws, hammers, wrenches, and for many other purposes where a tool possessing hardness and resistance to wear or abrasion is required.

High-speed steels are those steels of comparatively low carbon content which depend for their hardness on the use of tungsten and chromium. They also contain other metals, such as vanadium, cobalt, manganese and molybdenum.

High-speed steels are used in making all kinds of tools, especially lathe and shaper tools, milling cutters, drills, reamers, gas engine valves, and for all purposes where great efficiency, high-speed cutting and heat-resisting qualities are required.

The use of high-speed steel has had a great influence on machine shop practice in that tools made from this steel are able to maintain a cutting edge when heated to a temperature that would ruin the best of carbon tool steels. This ability to maintain hardness when heated to a high temperature has resulted in an enormous increase in the speed of cutting. High-speed steels vary considerably in their composition. Analysis of many steels show the following range:

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Carbon ..... 0.55— 0.85 per cent.
Tungsten .....12.00—20.00 per cent.
Chromium ..... 1.00— 8.00 per cent.
Vanadium ..... 0.50— 2.50 per cent.
Cobalt, varying amounts.
Molybdenum, varying amounts.

Often, other metals are alloyed with high-speed steels. Some special steels may have a greater or less amount of the constituents in their compositions.

The part played by tungsten in high-speed steels is to raise the temperature at which hardening is effected and also to raise the temper temperature. A straight carbon tool steel will begin to

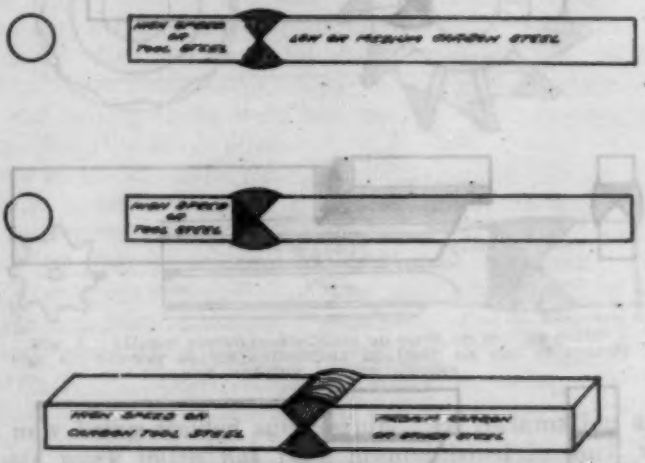


Fig. 1. (Upper two sketches)—Welding high speed steel bits to medium carbon steel shanks for reamers and other tools
Fig. 2. (Lower sketch)—Welding high speed or carbon tool steel to medium carbon or other steel

soften at 400 to 500 deg. Fahr., and at 1100 deg. Fahr. it will be annealed and not fit for a cutting tool. The addition of tungsten, however, not only permits retention of the hardness incurred by rapid cooling, but also under proper conditions considerably increases the hardness when the steel is reheated to a temperature as high as 1100 deg. Fahr. This means that it is possible to use a speed of cutting such that the cutting edge of the tool will reach a dull red color. The addition of chromium to the steel containing tungsten not only greatly increases the hardness of the steel but also produces a lowering of the temperature at which secondary hardness takes place on tempering.

In the carbon tool steel the amount of carbon in the steel is dependent upon the purpose for which the steel is used.

From 0.60 to 0.85 per cent carbon is used in steel for hammers, rivet sets, blacksmith tools, forge dies and all tools where a great toughness combined with the proper hardness is required.

From 0.85 to 0.95 per cent carbon is used in steel for pneumatic chisels, punches, shear blades and so forth. From 0.95 to 1.15 per cent carbon is used in steel for milling cutters, mandrels and general machine shop tools; in fact, all tools requiring a keen cutting edge combined with hardness and toughness. From 1.15 to 1.25 per cent carbon is used in steel for lathe and shaper tools, drills, taps, reamers and all tools requiring a keen cutting edge combined with great hardness. Steel containing above 1.25 per cent carbon is used where great hardness is the main requisite. High-carbon tool steel may also have other metals alloyed with it, such as vanadium.

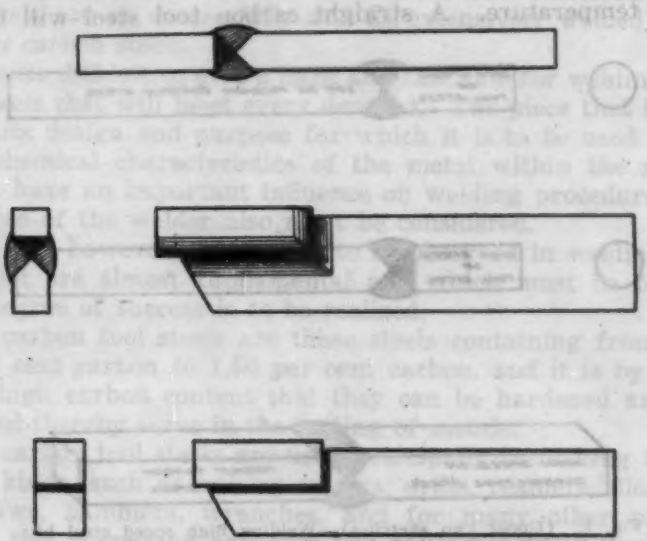


Fig. 3. (Upper two sketches)—Method of welding high speed bits to soft steel shanks for lathe and shaper tools
Fig. 4. (Lower sketch)—A method of brazing high speed steel bits to medium carbon steel shanks for lathe tools

In the welding of tool steel the carbon content is an important factor to consider. A steel with a carbon content of from 0.60 to 0.85 per cent may be welded fairly easily by a welder who exercises ordinary care and is at all familiar with steel welding. With a carbon content of from 0.85 to 1.00 per cent the welding is more difficult, and from 1.00 to 1.50 per cent great care is required in making a weld, and a degree of care that can only be attained by experience in welding steels with such high carbon content.

All metal cutting tools are subjected to a number of stresses, all of which are important factors in the proper selection of the steel for the tool and also because of their effect on the welds. Drill, reamers and taps are subjected to torsion stresses and also to tension stresses. Lathe and shaper tools are subjected to transverse stresses. Milling cutters have to endure nearly every type of stress. The cutting edge of all metal cutting tools especially

must not only have good wearing qualities but because of its extreme fineness and its functioning in the cutting of metals must endure practically every stress. It is because of this fact, together with the welding qualities of the metal, that the welding of carbon tool steels and high-speed steels becomes a problem that has been harder for many welders to solve than the welding of mild carbon steel.

Both high carbon tool steels and high-speed steels have been

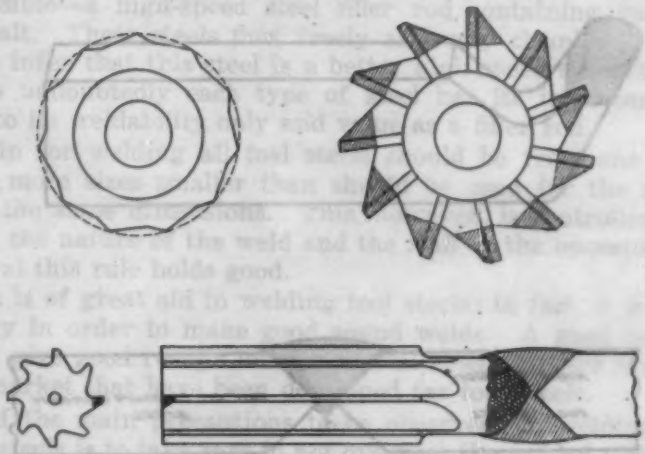


Fig. 5. (Upper sketch)—Building up teeth on milling cutter
Fig. 6. (Lower sketch)—Building up teeth on end of reamer and welding broken shanks

and are now being welded successfully. In reclamation and general repair work much has been accomplished in such work as building up the faces of hammers worn and chipped in use. Wrenches with broken or worn jaws are being reclaimed. Milling cutters and reamers with broken teeth are repaired. See Figs. 5 and 6. Form tools are being reclaimed by building up the worn part with high-speed and tool steel and regrinding to shape.

Lathe tools for use in heavy cutting are being made by welding a high-speed steel bit to a medium carbon shank, as in Fig. 3. Reamers are also made in this manner. See Fig. 1. Milling cutters and other steel cutting tools have been made by building up the cutting edge on a law chrome or medium carbon steel center. Gasoline engine valves are made by welding low chrome steel stems to high-speed steel heads, as shown in Fig. 11.

Another use for both high carbon tool steel and high-speed steel is for building up parts of machinery, and so forth, which require a hard, erosion-resisting surface.

In the welding of high-speed steels I wish also to include stellite, an alloy of cobalt, iron, chromium and tungsten which is used for similar purposes as are the high-speed steels.

One of the main requisites in welding high-carbon and high-

speed steels are the torch and tips. They should be of a construction that will assure a good mixing of the gases before burning and a low gas ratio. Torches of this type are available.

The flame adjustment is also important. It should be a reducing flame for high-speed steels, stellite and the higher carbon steels. With the carbon steels this flame adjustment somewhat depends upon the carbon content. The lower carbon tool steels may be welded with a neutral flame, taking care that it is non-oxidizing.

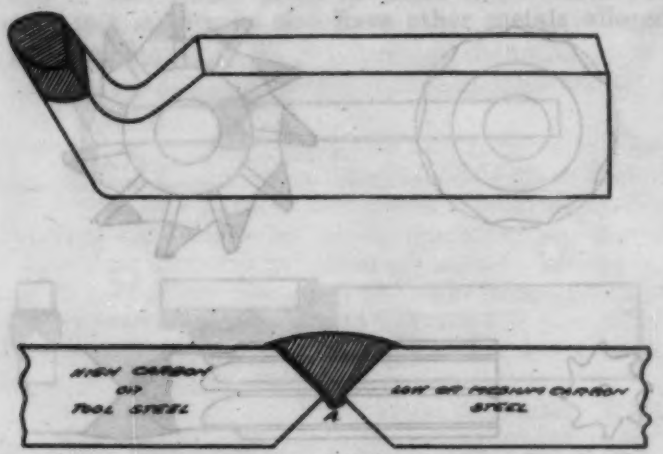


Fig. 7. (Lower sketch)—Metal and oxide extruded through vee at A should be removed before welding the opposite vee
Fig. 8. (Upper sketch)—Building up cutting edge of lathe tool with high speed steel

The higher carbon steels, however, require an excess of acetylene in the welding flame. It is difficult to describe the exact flame characteristic. Experience only can tell the welder the flame desired. It will vary slightly with the type of steel being welded.

The welding rod is also important. In the high carbon steels it should be of high-grade material, and not lower in carbon content than the steel to be welded. If the welding metal is to become part of the cutting edge it is preferable that the steel contain a slightly higher carbon content. This, however, is less important than that it be at least of as high a carbon content. Any great departure in the carbon content from that in the steel to be welded will make the welded metal either too soft to take the proper temper in the heat treatment, or too brittle to withstand the stress to which it will be subjected in use. There are many welds that can be made in tool steel where a much lower carbon steel can be used. This must be determined by the functioning of the tool itself as these welds are at a point remote from the cutting edge.

In preparation of the part to be welded a rather wide bevel on tool steel is preferable. This will make unnecessary the fusing

down of the sides in making the weld. All parts to be welded should be carefully cleaned of dirt and rust.

The welding of high-speed steels while in general is not dissimilar to welding high carbon tool steel, requiring the same method of preparation and a welding rod that will flow freely and not cause blowholes. Heavy oxides from the chromium and tungsten usually form on the surface of high-speed steels in the melting operation, and blowholes become difficult to eliminate. It will be found advantageous to use, wherever possible—and it is usually possible—a high-speed steel filler rod containing vanadium and cobalt. These steels flow freely and very cleanly. I do not mean to infer that this steel is a better high-speed steel than any other as undoubtedly each type of steel has its important field. I refer to its weldability only and value as a filler rod.

The tip for welding all tool steels should be from one to two or even more sizes smaller than should be used for the average steel of the same dimensions. This, however, is controlled somewhat by the nature of the weld and the skill of the operator. But in general this rule holds good.

A flux is of great aid in welding tool steels; in fact, it is almost necessary in order to make good sound welds. A good cast iron flux will give good results on carbon tool steels. There are fluxes on the market that have been developed for tool steels.

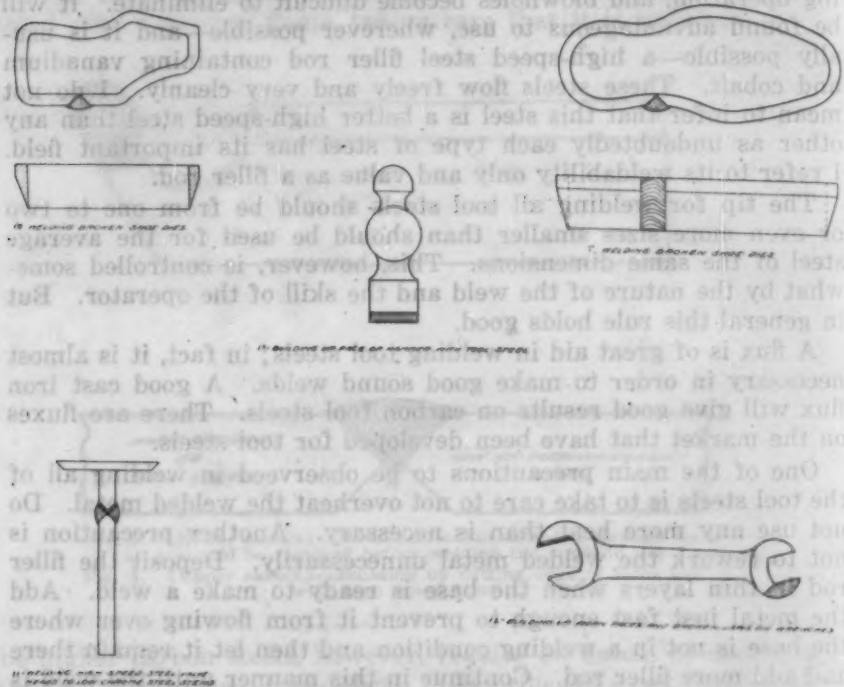
One of the main precautions to be observeed in welding all of the tool steels is to take care to not overheat the welded metal. Do not use any more heat than is necessary. Another precaution is not to rework the welded metal unnecessarily. Deposit the filler rod in thin layers when the base is ready to make a weld. Add the metal just fast enough to prevent it from flowing over where the base is not in a welding condition and then let it remain there and add more filler rod. Continue in this manner until the weld is completed. It is the frequent reworking of the weld metal that causes the most of the defective welds. It causes blowholes, and creates an excessive film of oxide that collects on the surface. The success or failure of the weld depends upon properly adding the filler rod.

When the welded joint is of the double vee type there will be some metal extended through the bottom of the vee when the first half of the weld is completed, Fig. 7. This extended metal is composed, to a great part, of oxides. It is better to remove this extended metal before starting the second half of the weld either by flowing it out of the vee with the torch or by any other means that will remove the oxide and prevent an excessive accumulation of it in the weld.

The high-speed steel should not be melted down in making a weld, but rather the filler rod should be added to the surface, Fig. 2, taking care, of course, that the surface is in the proper state of fusion to take a weld. For this reason a wide bevel is of great

advantage. The bevel should not be less than 45 degrees, and the combined vee not less than 90 degrees.

Where a carbon tool steel or high-speed tool steel bit is welded to a medium carbon steel shank or base and it is not desirable or practicable to bevel the bit, it is best to prepare the bit first by building up over the surface a conical or beveled section with the filler rod, Figs. 1 and 3. The filler rod should be of nickel or va-



Figs. 9 to 13

nadium steel in a weld of this type. However, other steels may be used as the filler. The bit is then placed in position on the shank or base and the same filler rod used to make the weld.

I have seen many failures in making these welds when the bit was not prepared in this manner, but have always met with success when the bit has been prepared as I have just described. This type of weld is used on special reamers, heavy lathe and shaper tools and so forth.

Lathe tools of the forged carbon tool steel type have been modified by building up the cutting ends with high-speed steel along the lines shown in Fig. 8. Milling cutters, Fig. 5, have not only been repaired by building up broken teeth but new cutters have been made by using a low chrome steel center and building up the teeth with the oxy-acetylene flame. As an aid in this work a form or mold was made of graphite, approximating the shape of the

teeth. The cutter base was mounted on a shaft or arbor so that it could be turned readily. The form was held in place and the weld made by carefully fusing the base and then filling up the form. These cutters were made in very short time and were highly successful. The filler rod was a cobalt high-speed steel. No heat treatment was required after welding. The cutter was ground into shape and put in service. In a test for comparison with a similar cutter made of high-speed steel by the casting process and a forged high-speed steel cutter the welded cutter gave approximately 60 per cent greater efficiency than the forged cutter, and about 30 per cent more than the one made by casting. The cutters used in the tests were 6 inches diameter by 1 inch face. The cut was 1 inch deep and was run at the highest speed possible. Identical results were obtained by the lathe tools built up as described.

Carbon tool steels after welding must be heat treated by hardening and tempering. A tool after welding requires to be normalized or annealed by cooling slowly before it is retempered. This may be done by heating with the welding flame and then covering the tool with dry ashes, lime or other heat-insulating material.

Hammering of the weld after completion must be done with caution. It is beneficial to a weld in the carbon tool steels where the parts welded together and the filler rod is of the same composition, but where any part including the deposited metal, is of different types of steel or even of the same type but of considerable difference in carbon content, hammering should not be attempted. Hammering of a weld where carbon tool steel is welded to low or medium carbon steel or to high-speed steel or where high-speed steel is welded to any other type of steel will cause the joint to break apart due to the difference in malleability of the metals. Many failures in welding these steels can be attributed to hammering the weld.

It has been my good fortune to be able to devote several months to welding tool steels. Much of this work was in development of new tools to which the oxy-acetylene process appeared to be applicable and much of which was in reclaiming defective tools. Some of the work was unsuccessful but much of it was highly successful. The failures were mainly due to commercial impracticability rather than to failure or lack of success of the welding itself. It is often quite difficult, in fact, impossible usually, to reclaim a tool or piece of machinery by welding when the weld is in a place that has been finished to an exact dimension and it is not allowable to regrind the tool below that dimension.

In general, I should say that success in welding high-speed or carbon tool steel depends upon the proper preparation of the steel for welding, the use of the proper filler rod, the proper flame characteristics, the size of welding tip and care in making the weld.

Failure is the result not only of not taking the proper precaution in preparing the work, selection of the proper filler rod and care in welding but to lack of experience and the inherent difficulty of welding many of the high-speed and high carbon steels.

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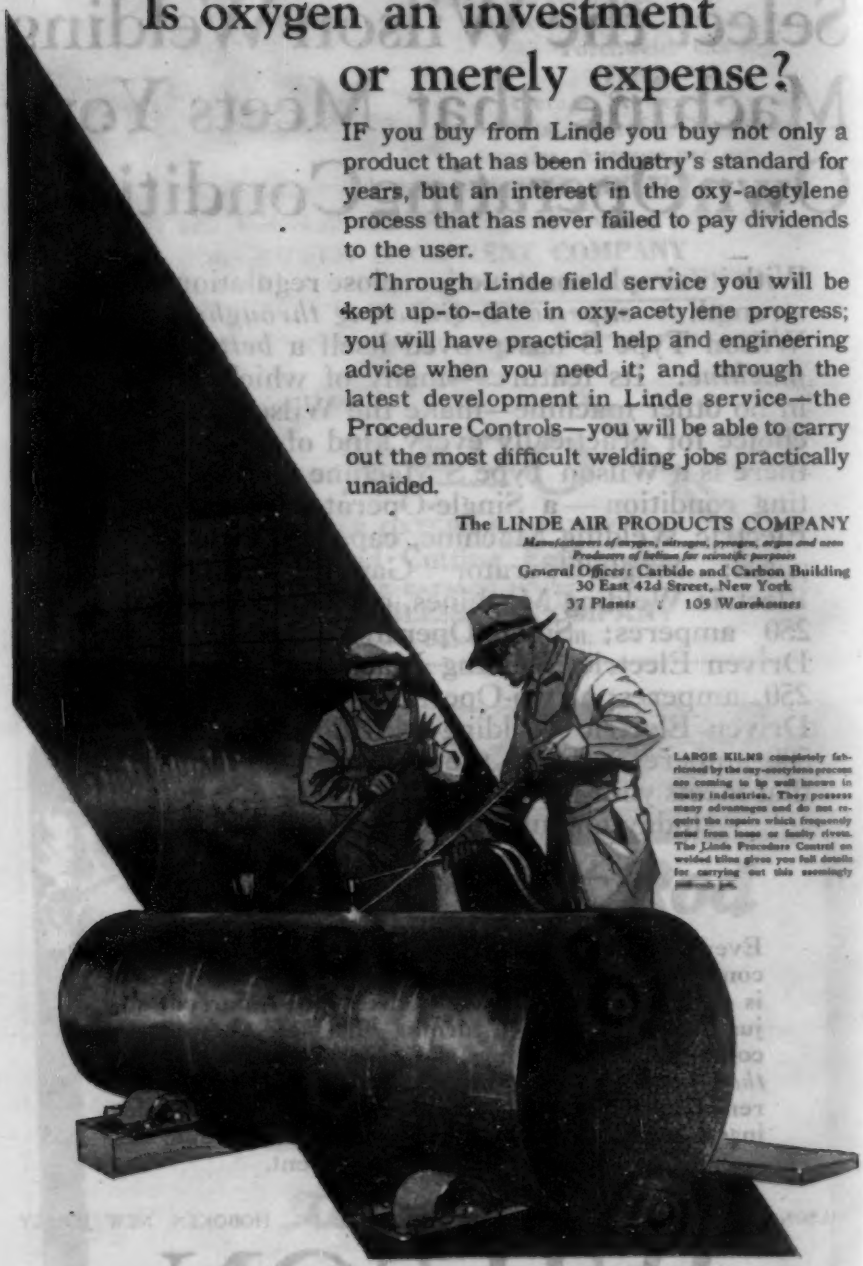

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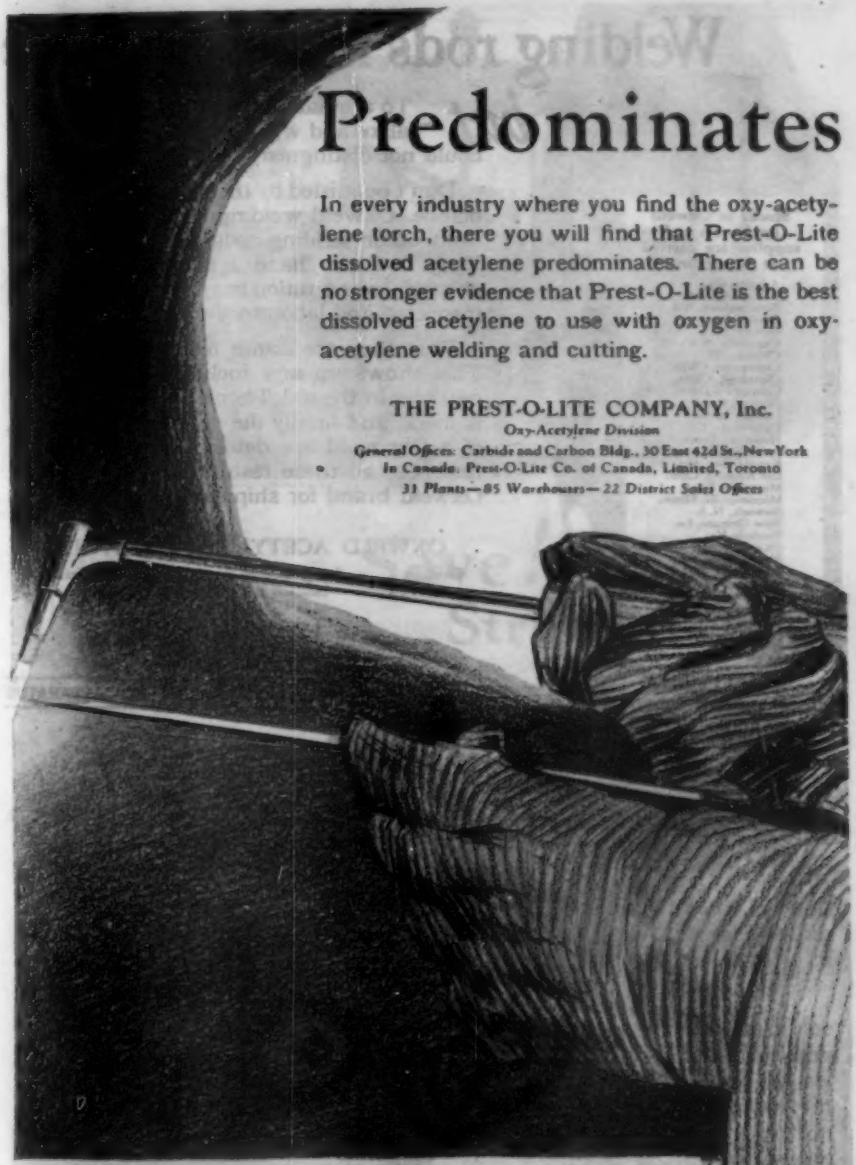

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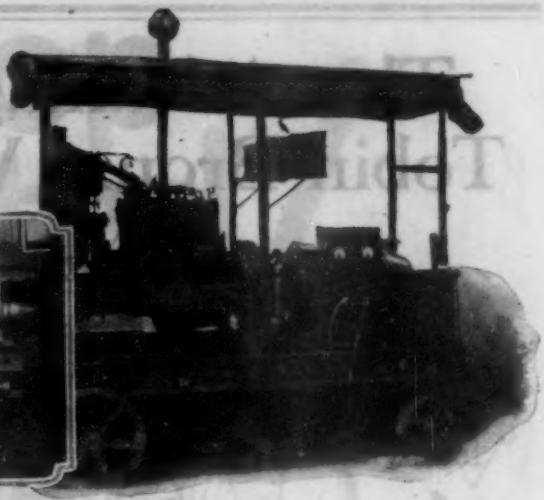

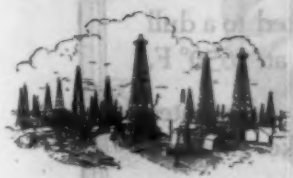

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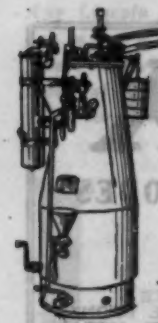

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